State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems in 2013

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by

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Abstract

Fisheries and Oceans Canada conducts annual reviews of ocean and marine ecosystem conditions in Pacific Canadian waters and the broader North East Pacific. The workshop to review conditions during 2013 took place on 19 February 2014 at the Pacific Biological Station, Nanaimo, B.C., Canada. Overall, 2013 appeared to be a year of transition in physical oceanographic conditions. It was dominated by cooler temperatures during the first half of the year then switched to warmer conditions during the second half of the year. By the end of 2013 and into early 2014, exceptionally warm and fresh conditions, and weak winds, were observed in the Gulf of Alaska, creating very strong vertical stratification. Warm conditions also occurred along the outer B.C. coast during the latter half of the year, making 2013 warmer on average than 2012. These warmer temperatures, along with weak winds, contributed to very weak downwelling conditions along the west coast of Vancouver Island at the end of 2013. Biological responses to these changing physical conditions were muted, likely due to time lags from physics to fish. More warm water zooplankton occurred during summer and fall 2013 along the west coast of Vancouver Island than earlier in the year. In contrast to recent years, Pacific Sardine were not observed during two summer surveys along the west coast of Vancouver Island, and there was no commercial fishery for Pacific Sardine in 2013, capping a 7 year decline in sardine abundance in B.C. A special highlight were the sightings of two different North Pacific Right whales along the outer B.C. coast in 2013, the first confirmed observations of these animals in B.C. waters in 62 years. Stocks of Sockeye Salmon that enter the ocean into the California Current Upwelling Domain continued to increase during 2009-2012. The total survival of Sockeye Salmon which enter the Strait of Georgia as young and return to the Fraser River as adults continued to remain average for most stocks in the 2011 ocean entry (2013 return) year. In addition, the marine survival of one year old Sockeye Salmon from Chilko Lake in the B.C. Interior has continued to improve from the lowest survival on record for this stock in the 2007 ocean entry year (2009 return year).

Resumé

Pêches et Océans Canada effectue une revue annuelle des conditions des écosystèmes océaniques et marins dans les eaux canadiennes du Pacifique et sur une partie du nord-est du Pacifique. L'atelier ayant pour objectif de réexaminer les conditions de 2013 a eu lieu le 19 février 2014 à la Station biologique du Pacifique, Nanaimo, Colombie-Britannique, Canada. Dans son ensemble, 2013 semblait une année de transition dans les conditions océanographiques physiques. Elle a été dominée par des températures plus fraîches durant la première moitié de l'année suivit par des conditions plus chaudes durant la seconde moitié de l'année. À la fin de 2013 et au début 2014, les conditions exceptionnellement chaudes et fraîches ainsi que des vents faibles, ont été observés dans le golfe d'Alaska, créant une stratification verticale très forte. Des conditions chaudes ont également eu lieu le long de la côte extérieure de la Colombie-Britannique au cours de la seconde moitié de l'année, faisant de 2013 une année plus chaude en moyenne que 2012. Ces températures plus élevées combinées avec des vents faibles ont contribué à de faibles courant descendants le long de la côte ouest de l'île de Vancouver à la fin de 2013. Les réponses biologiques à ces changements physiques ont été tempérés, probablement en raison des décalages entre les conditions physique et les poissons. Il y avait plus de plus zooplancton d'eaux chaudes le long de la côte ouest de l'île de Vancouver au cours de l'été et l'automne 2013 que plus tôt durant l'année. Contrairement aux dernières années, les Sardines du Pacifique n'ont pas été observées au cours de deux campagnes d'échantillonnage qui on eu lieu le long de la côte ouest de l'île de Vancouver durant de l'été. Il n'y a eu aucune pêche commerciale de la Sardine du Pacifique en 2013 suite à un déclin de 7 ans de l'abondance de la sardine en Colombie-Britannique. Un des points saillants était l'observation de deux Baleines Franches du Pacifique Nord le long de la côte extérieure de la Colombie-Britannique en 2013, soit les premières observations confirmées de ces animaux dans les eaux de la Colombie-Britannique en 62 ans. Les stocks de Saumons Rouges qui entrent dans l'océan dans le domaine de la remontée du courant de Californie ont continué d'augmenter au cours de 2009-2012. La survie totale de Saumons Rouges qui entrent dans le détroit de Georgia comme saumoneaux et retournent au fleuve Fraser en tant qu'adultes a demeuré autour de la moyenne pour la plupart des stocks qui sont entrés dans l'océan en 2011 (retour de 2013). De plus, la survie en mer des saumoneaux d'un an des Saumons Rouges du lac Chilko, un stock de l'intérieur de la Colombie-Britannique, a continué de s'améliorer depuis la plus faible survie enregistrée pour ce stock lorsqu'ils sont entré dans l'océan en 2007 (retour de 2009).

1. Highlights

- A one day meeting to review available information on ocean conditions in 2013, and how they compare with previous years, was held at the Pacific Biological Station, Nanaimo, B.C., on 19 February 2014.
- Overall, physical ocean conditions appeared to be in transition in 2013 with cooler temperatures dominating in the first half of the year then switching to warmer conditions during the latter half of the year.
- Biological responses, however, were more muted (likely because of time lags between physical and biological systems), although with some very notable exceptions (see below).

NE Pacific

- Central Northeast (NE) Pacific experienced cool temperatures early in the year, but warmed in the fall and became very warm at the end of 2013 and into early 2014. This warming, along with weak winds at the end of 2013, resulted in very strong vertical stratification in the central Gulf of Alaska during summer 2013 that continued well in to early 2014.
- No strong differences were observed in phyto- or zooplankton species composition in the central Gulf of Alaska in 2013 from previous years.

Outer BC coast

- 2013 was warmer than 2012 at all coastal measurement locations; the first half of 2013 was generally cooler than the 30-year (1981-2010) average with the second half being warmer.
- Weak winds and warmer temperatures contributed to very weak downwelling conditions along the west coast of Vancouver Island at the end of 2013; this year had the lowest cumulative downwelling conditions since measurements began in 1967.
- As an annual average, the zooplankton community composition reflected predominantly cool conditions. However, and consistent with the change in ocean conditions between the first and second halves of 2013, the zooplankton composition showed greater abundances of warm water zooplankton in summer and fall 2013 than earlier in the year.
- Pacific Sardine were not observed during two summer surveys along the west coast of Vancouver Island, and there was no commercial fishery for Pacific Sardine in 2013, capping a 7 year decline in sardine abundance in B.C.
- Stocks of Sockeye Salmon that enter the ocean into the California Current Upwelling Domain continued to increase during 2009-2012, reaching near record returns.
- Two individual North Pacific Right whales were observed in Canadian Pacific waters in 2013, the first confirmed observations in 62 years.

Strait of Georgia

- Timing of the spring phytoplankton bloom in the Strait of Georgia appeared to return towards earlier blooms after a series of late blooms from 2007 to 2012.
- Total survival of Sockeye Salmon to the Fraser River continues to remain average for most stocks in the 2011 ocean entry (2013 return) year. This is similar to survivals in recent years, which include the ocean entry years from 2008 to 2011 (2010 to 2013 return years) and contrasts with the previous period of declining productivity in the late-

1990s and the extremely poor productivity that occurred in the 2007 ocean entry year (2009 return year).

- Marine survival of one year old Sockeye Salmon from Chilko Lake in the B.C. Interior (which comprise, on average, 94% of their total smolt numbers) has also improved in recent years, relative to the lowest survival observed on record for this stock in the 2007 ocean entry year (2009 return year).

2. Introduction

Fisheries and Oceans Canada, Pacific Region, conducts annual reviews of physical, chemical and biological conditions in the ocean, to develop a picture of how the ocean is changing and to help provide advance identification of important changes which may potentially impact human uses, activities, and benefits from the ocean. These reviews take the form of one to two day meetings, usually held in February or March of the year following the year under review. These review meetings began in 2000 to assess conditions in 1999; reports from these reviews are available at
http://www.pac.dfo-mpo.gc.ca/science/oceans/reports-rapports/state-ocean-etat/index-eng.html
or by conducting a web search using the search terms: "DFO, Pacific, Ocean Status Reports".

Reviews and reports since 2007 were conducted under the direction of the Fisheries & Oceans Canadian Science Advice Secretariat (CSAS). The status of these State of the Pacific Ocean reviews within the CSAS process is under consideration at present and as a result the 2014 review was held as a stand-alone workshop; the report is presented here as a Fisheries & Oceans Canada Technical Report. The workshop took place on 19 February 2014, at the Pacific Biological Station, in Nanaimo, B.C. The agenda for the workshop is presented in Appendix 1, and the participants are listed in Appendix 2.

This technical report presents the highlights and summaries of the presentations and discussions at the workshop. These summary reports are not peer reviewed, and present the status of data, interpretation, and knowledge as of the date of this workshop. For use of, or reference to, these individual presentations, please contact the individual authors.

3. Overview and Summary

This section presents a brief overview and summary of the main findings of the presentations and workshop discussions. It is separated into NE Pacific, Outer B.C. Coast, and Strait of Georgia (Fig. 3.1). Findings reported here are referenced to the individual reports in the next sections, and readers are advised to read those sections for details. Overall, 2013 showed strong transitions in physical ocean conditions during the year, with the biology mostly continuing recent patterns, although with some notable exceptions. The lack of strong changes in the marine life may be due to lag effects, such that the biology integrates conditions over the previous one to several years and therefore may not have had time to respond to the changes in the latter half of 2013.

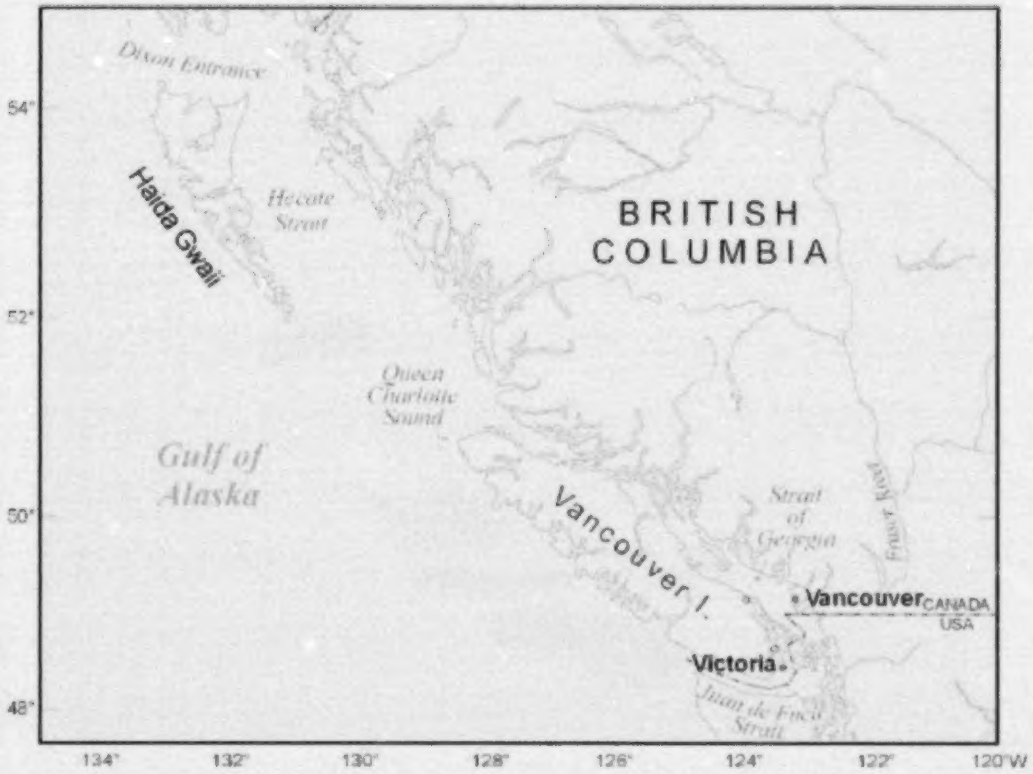

Figure 3.1. Map of Canadian Pacific waters discussed in this report.

Northeast Pacific

The average surface air temperature for the Earth (land and ocean) in 2013 was tied for the fourth warmest year since direct measurements were started in 1880. For much of the 2007 to 2013 period conditions in Canadian Pacific waters were cool, typical of La Niña and the cool phase of the Pacific Decadal Oscillation. Shifts in the winds patterns in summer 2013 carried very warm surface waters into B.C. coastal regions, with some stations recording their highest sea temperatures in September in 40 years. By late 2013, further shifts in wind patterns pushed this warm water towards the middle of the Gulf of Alaska (Crawford, this volume).

Very warm conditions in the upper waters of the central Gulf of Alaska continued through the winter of 2013 – 2014 (data to the end of February 2014). Temperature conditions in January 2014 were over 4 standard deviations above the mean January value (1981-2010), and salinity was over three standard deviations below the January mean (Freeland, this volume). In addition, wind speeds along the B.C. continental shelf and adjacent open ocean were relatively weak, with 2013 having the second lowest October-to-January average wind speeds in the 27 years on record (1993 was slightly lower). The consequence of these very warm conditions and weak winds at the end of 2013 was very strong vertical stratification and weak vertical mixing. Note that the upper layer nutrient concentrations that support biological productivity throughout most of the year in this area are largely replenished by the strong vertical mixing that usually occurs during winter (Freeland, this volume).

Zooplankton in the central Gulf of Alaska are sampled several times a year by the Continuous Plankton Recorder (CPR) Program (Batten, this volume). While data for the latter half of 2013 were provisional at the time of writing, results from available samples show that the abundance of diatoms continued to be below average in 2013 (period of record 2000 to 2013). Mesozooplankton had somewhat higher than normal biomass during the first half of 2013, mostly due to increased abundances of large zooplankton such as euphausiids, large copepods, and hyperiid amphipods. These results appear to support the hypothesis that warm water, and smaller, copepods were becoming more abundant by the end of 2013.

Information on high trophic level species in the NE Pacific is available for albacore tuna (Holmes, this volume). 2013 was a "better than average" year for albacore tuna in the NE Pacific. Catch rates of young (2-4 year old) albacore off B.C. and in the NE Pacific were above average during the fishing season (July to October; average of 79 fish per day in 2013 compared with 66 fish per day from 2000-2009). It is suggested that improved catch rates in 2013 relative to 2012 were due to greater overlap in space and time between warmer surface waters and enhance food production along the continental shelf due to above average upwelling.

Outer BC coast

The average daily sea surface temperature at most observation locations along the B.C. coast was warmer in 2013 than in 2012, by about 0.5°C. In comparison with long term trends (1981-2010) sea surface temperatures along the B.C. coast were somewhat cooler than normal for the first half of 2013 but above normal in particular during summer and fall. Long term annual temperature trends at three locations spread along the B.C. coast are shown in Fig. 13.6. Average daily sea surface salinity was more saline in 2013 (by about 0.6 salinity units) compared with 2012 at most B.C. stations, and was closer to the 30 year average in 2013 than in 2012 (Chandler, this volume).

The annual pattern of wind-driven upwelling was unusual during 2013 (Dewey and Mihaly, this volume). Downwelling in the winter season (typically to mid-April, when winds are predominantly from the SE) was weak in 2013, and was followed by a moderate upwelling season (dominant winds from the NW) with the majority of upwelling occurring in July. This peak was followed by weak downwelling to the end of the year. The result was that 2013 had very low net annual (January to December) cumulative downwelling of only 500 m^3/s/100 m of coastline, compared with the long term (1967-2012) average of 10,000 m^3/s/100 m of coastline.

Biological responses to these conditions were muted. Zooplankton species composition followed the offshore pattern, with mostly cool water taxa during the first half of the year but with warm water, smaller sized taxa becoming much more abundant in the latter half of the year (Galbraith et al., this volume). In addition, the large subarctic copepods tended to have below normal biomass in 2013 on the continental shelf in 2013 compared with previous years. Small mesh bottom trawl multi-species surveys conducted off the west coast of Vancouver Island found that the species composition of demersal and benthic fish and invertebrates sampled (in May) during 2013 was similar to that from 2010-2012, and that Smooth Pink Shrimp populations continued to increase from their recent low abundance in 2011. This latter observation largely represents pink shrimp recruitment patterns from two years previous (Perry et al., this volume). Pacific Herring stocks in all areas of the B.C. coast continued to increase in 2013, driven by above average recruitment success of herring in recent years (Boldt et al., this volume). In contrast, no Pacific Sardine were captured in two DFO research surveys conducted in summer off the west coast of Vancouver Island (e.g. Figs. 18.2 and 20.2) and there were no commercial landings of Pacific Sardine in 2013, apparently due to a lack of this species in B.C. waters. This

Pacific Sardine stock is mostly located in U.S. waters, occurring in Canadian waters as summer/fall migrants. The low abundance of Pacific Sardine in B.C. waters in 2013 is believed to be due to cooler ocean temperatures early in the year, a contracted northward migration, and to reduced population abundance in U.S. waters (Flostrand et al., this volume).

The average catches of juvenile salmon (Sockeye, Coho, Chinook) during fishery-independent surveys off the west coast of Vancouver Island in 2013 were lower than catches during 2012 and were at or below their 1998-2013 average values. In contrast, catches of juvenile Chum Salmon increased in 2013 compared with 2012 and remained above their 1998-2013 average. The growth rates (May to October) of juvenile Coho off the west coast of Vancouver Island in 2013 also decreased from 2012 and were slightly below their 1998-2013 average, suggesting that marine survival of these Coho stocks returning in 2014 may be at or below their 1998-2013 average (Trudel et al., this volume).

The returns of all Sockeye Salmon indicator stocks along the B.C. coast were generally similar in 2013 to pre-season expectations. Southern B.C. Sockeye stocks that enter the ocean into the northern California Current Upwelling Domain (Okanagan and Barkley stocks) have shown a rapid rebuilding to near-record returns in 2009-2012. In contrast, northern B.C. Sockeye stocks continued their decade-long below average return through 2013 (Hyatt et al., this volume).

A highlight of 2013 was the confirmed sighting of a North Pacific Right Whale in Canadian Pacific waters, off the northern coast of Haida Gwaii, followed quickly by the confirmed sighting of a second individual off the west coast of Vancouver Island (Pilkington and Ford, this volume). These were the first confirmed sightings of this species in Canadian waters in 62 years. The Eastern Pacific Right Whale population is the smallest whale population in the world (among those species for which population estimates are available) and faces serious risk of extirpation.

Strait of Georgia

The occurrence of the spring phytoplankton bloom represents the start of the productive season in the Strait of Georgia. Its timing, whether it is early or late in any year, can have important implications for the growth and survival of marine and anadromous animals, such as herring and salmon. The timing of the spring bloom in the Strait of Georgia is being analysed by four programs reported in this volume. Allen et al. (this volume) have developed a model which simulates the timing of the spring phytoplankton bloom in the Strait of Georgia, defined by the drawdown of nitrate. This model is based on the amount of incoming sunlight and the depth over which the phytoplankton are mixed. Their model indicates a slightly earlier bloom in 2013 (late March) compared with blooms from 2006 to 2012. Gower (this volume) estimates the timing of the spring phytoplankton bloom from satellite observations of ocean colour. He estimates the typical range of dates for the start of the bloom from early March to early April. For 2013, the satellite images showed an extensive spring bloom in the Strait of Georgia from 18 March to 16 April. Costa et al. (this volume) analysed the timing of the spring phytoplankton bloom for three regions of the Strait of Georgia (south, central, north). For 2013, they found the bloom initiation in the north and central regions was similar (30 March to 7 April). The spring bloom in the south Strait of Georgia region occurred about 2 weeks later than in the rest of the Strait. In situ observations of phytoplankton concentrations (as chlorophyll *a*) in spring 2013 are in general agreement with the satellite and plankton model observations, indicating that the spring bloom had occurred by the time of the survey in April. In addition, chlorophyll concentrations tended to be below the 2004-2012 average concentrations in much of the Strait of Georgia during summer and fall in 2013 (Peña and Nemcek, this volume).

Fraser Sockeye salmon survival has generally returned to average in recent years (2008 to 2011 ocean entry years), following the period of declining trends in the 1990's and amongst the lowest survival on record in the 2007 ocean entry year (2009 return year). Similarly, marine survival of one year old smolts from Chilko Lake in the B.C. Interior (assessed since 1954), has improved relative to the exceptional poor survival in the 2007 ocean entry year (2009 return year) (Grant and MacDonald, this volume). Recent work conducted on the survival of the larger two year old Chilko smolts (which comprise, on average, 6% of Chilko smolts) using acoustic tags, provides some indication of survival of these fish from the outlet of Chilko Lake to Queen Charlotte Sound. For the period of time this work was conducted, survival in 2013 was higher than the previous three years assessed (2010-2012) during the downstream migration in the Fraser, and was lower in the Strait of Georgia and Queen Charlotte Sound (Rechisky et al., this volume).

In terms of returning salmon, and consistent with the expectation of abundant returns of Sockeye to the Fraser River system in 2014 (as a result of the exceptional brood escapement in 2010), the return of 'jacks' (sexually mature salmon that return at an earlier age) to the Fraser River in 2013 was at the high end of previously observed jack returns (Grant and MacDonald, this volume).

Other information offered during the concluding discussions, but not necessarily provided in any of the formal presentations, included the following:

- frequent observations of numerous 'jack' salmon returns in 2013 along the entire B.C. coast;
- very high returns of Pink Salmon in 2013;
- the first time since 1994 that 'blueback salmon' (small Coho passing from the grilse stage to maturity) were caught in the Strait of Georgia recreational fishery (for many years prior to 2013 these fish had migrated to the west coast of Vancouver Island).

Several issues were identified which need further discussion and/or consideration, perhaps in future State of the Pacific Ocean workshops. These include:

The issues of how 'best' to represent and capture the variable timing of the spring phytoplankton bloom in the Strait of Georgia (the present three approaches appear to provide slightly different measures of this start);

- how to "best" and optimally sample highly variable features along the B.C. coast, in particular chlorophyll;
- the need to monitor ecologically important but non-commercial species and include them in these annual review workshops;
- more information on direct anthropogenic stressors of these systems along the B.C. coast.

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Northeast Pacific

4. Global temperature in 2013, and anomalies in the Gulf of Alaska.

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The average surface temperature of the earth, both land and ocean, was warm in 2013 compared to an average over the 20th century. According to the US National Oceanic and Atmospheric Administration, the year 2013 tied for 4th warmest since 1880. A graph of global temperature anomaly in Fig. 4.1 shows the warming signature of the surface of the earth for the past 134 years. There has been little warming of the surface since 2002, nor have temperatures declined over this period.

The most rapid increase in surface temperature was from 1976 to 1998 when the earth warmed by about 0.6 °C. Although the general increase in temperature at the surface of the earth has stalled over the past decade or so, the heat gained by the earth and ocean continues to increase. Most of the additional heat gained since 2000 has been in deep ocean waters rather than at the ocean surface. When ocean temperature at all depths is considered, rather than only at the ocean surface as shown in Fig. 4.1, an increase in temperature has continued since the year 2000.

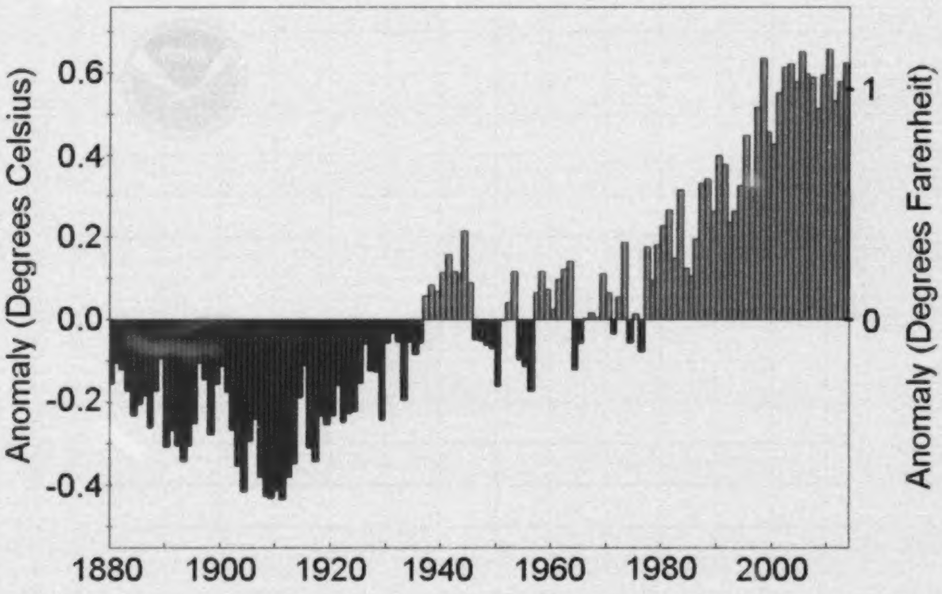
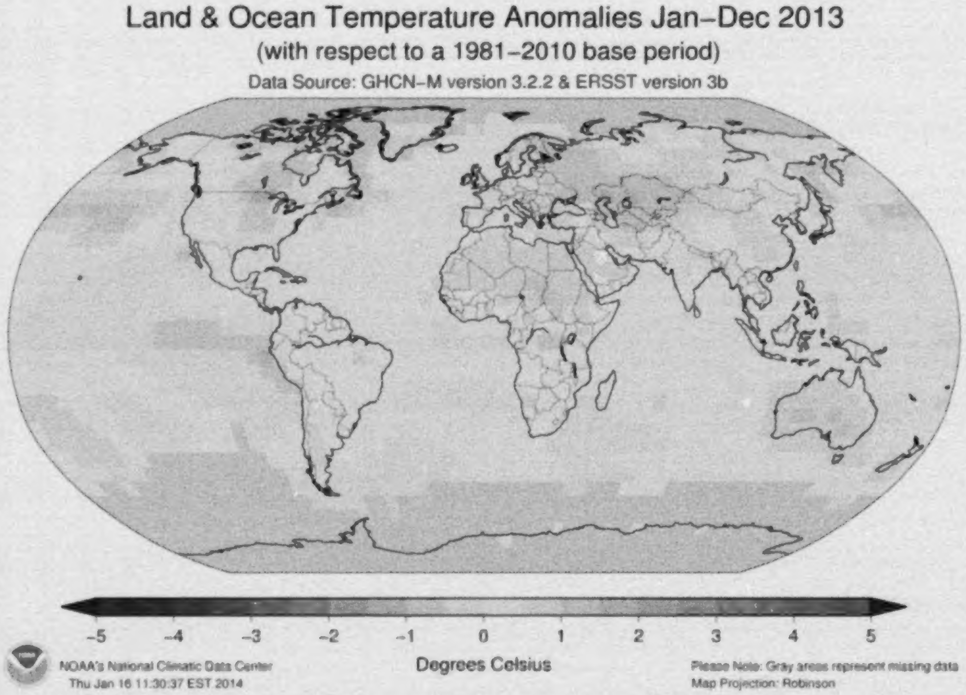


Figure 4.1. Global surface temperature anomaly from 1880 to 2013, with respect to a base period of 1901 to 2000. Source: National Oceanic and Atmospheric Administration (NOAA) http://www.ncdc.noaa.gov/cag/time-series/global/globe/land_ocean/ytd/12/1880-2013

The temperature anomalies of Fig. 4.1 are relative to an average over the 20th century, a rather arbitrary time period. Weather offices traditionally use a recent 30-year interval as a base period for normal temperature, with the period of 1981 to 2010 serving as the base period over which to compute normal or average temperature for 2013. A glance at Fig. 4.1 shows that the average temperature of 1981 to 2010 was considerably warmer than the average of 1901 to 2000 that was applied to Fig. 4.1.

The base period matters when temperature anomaly in the year 2013 is shown for regions of the earth in Fig. 4.2, where the base years are 1981 to 2010. The shading in Fig. 4.2 is mostly pink, indicating a warmer global surface than the 1981 to 2010 average, but even warmer shading would be required if the reference years were 1901 to 2000.

Most of the surface of the earth was warmer in 2013 than the 1981 to 2010 base period, especially over the central north and south Pacific Oceans, east Asia, Australia, and north Africa. A small strip of ocean along the west coast of Oregon to California is shaded blue, representing a cooler ocean surface. Central Canada and USA were relatively cool, as well as parts of western Europe. The relatively warm oceans west of British Columbia arrived in the summer of 2013 and were preceded by several years of relatively cool waters off our coast.


Land & Ocean Temperature Anomalies Jan–Dec 2013
(with respect to a 1981–2010 base period)
Data Source: GHCN-M version 3.2.2 & ERSST version 3b
-5
-4
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Degrees Celsius
NOAA's National Climatic Data Center
Thu Jan 16 11:30:37 EST 2014
Please Note: Gray areas represent missing data
Map Projection: Robinson

Figure 4.2. Map of the globe showing surface temperature anomalies (°C) in the year 2013 relative to a base period of 1981 to 2010. The colour bar at bottom shows the temperature anomaly scale, with pink and red for positive anomalies and relatively warm regions, pale blue and dark blue for negative anomalies and relatively cool regions. Grey areas represent missing data. Source: NOAA http://www.ncdc.noaa.gov/sotc/global/2013/13

Eastern Pacific since 2011

In the eastern Pacific Ocean, relatively cool sea surface temperature (SST) centred in the tropics has persisted in most years since 2007. The warmer SST to the west, mostly at higher latitudes, has also persisted since then. This pattern of SST is typical of La Niña conditions, and also typical of the cool phase of the Pacific Decadal Oscillation.

The features of Fig. 4.2 do not show how ocean temperature shifted rapidly along the BC coast within the year 2013. SST was mostly cool along the coast until mid-summer, at which time shifts in the wind carried very warm ocean surface water into coastal regions.

The progression of SST is shown in Fig. 4.3, from September 2011 to February of 2014. The blue regions in each panel of Fig. 4.3 reveal cool SST, whereas areas coloured red are relatively warm compared to the base period of 1981 to 2010. Note the dominance of blue along the west coast of Canada and USA from Sept. 2011 to Feb. 2013. These cool waters actually dominated from the year 2007 to summer 2013, interrupted only in early 2010.

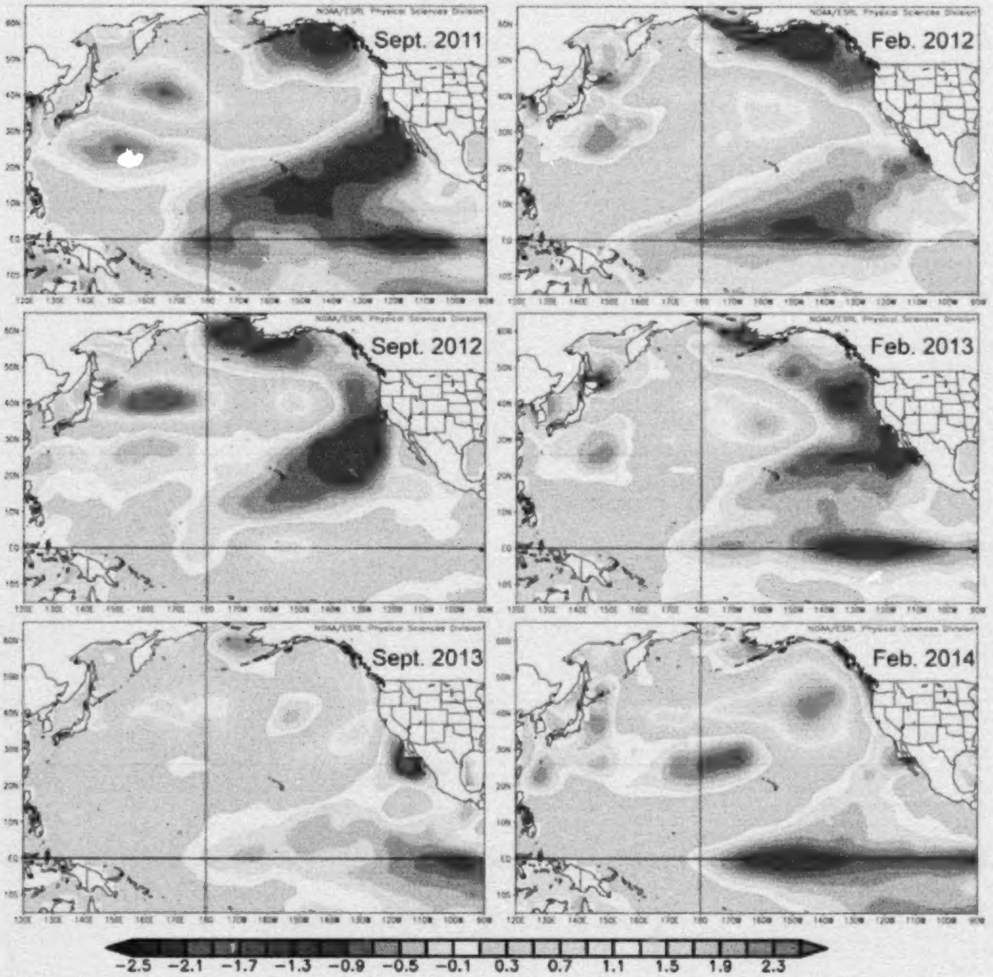

Figure 4.3. Anomalies of sea surface temperature (SST, °C) in the Tropical and North Pacific Ocean for February and September since 2011, with respect to a base period of 1981 to 2010. The temperature anomaly scale is at bottom. Land appears in white, shorelines are black. The equator and 180W meridian are black lines. Source: http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl

In August 2013 the weather pattern changed along the west coast and the shift in winds brought a few severe rainstorms into British Columbia in late August and early September, and also pushed warmer water right up to the coast. This warming is visible in the SST anomaly pattern of September 2013. Some coastal temperature readings for this month were among the highest recorded in 40 years. By November and December 2013 the weather pattern shifted again, with winds in mid-Gulf of Alaska pushing warm water north, and winds along the west coast pushing cool water south. The result, shown in the Feb. 2014 SST anomaly of Fig. 4.3, is a patch of very warm water in the middle of the Gulf of Alaska, but cool water in a narrow strip along the entire west coast from Alaska south to Baja California. The positive SST anomaly in mid-gulf was one of the highest ever recorded there. This pattern of SST anomaly was present from November 2013 right into early March 2014.

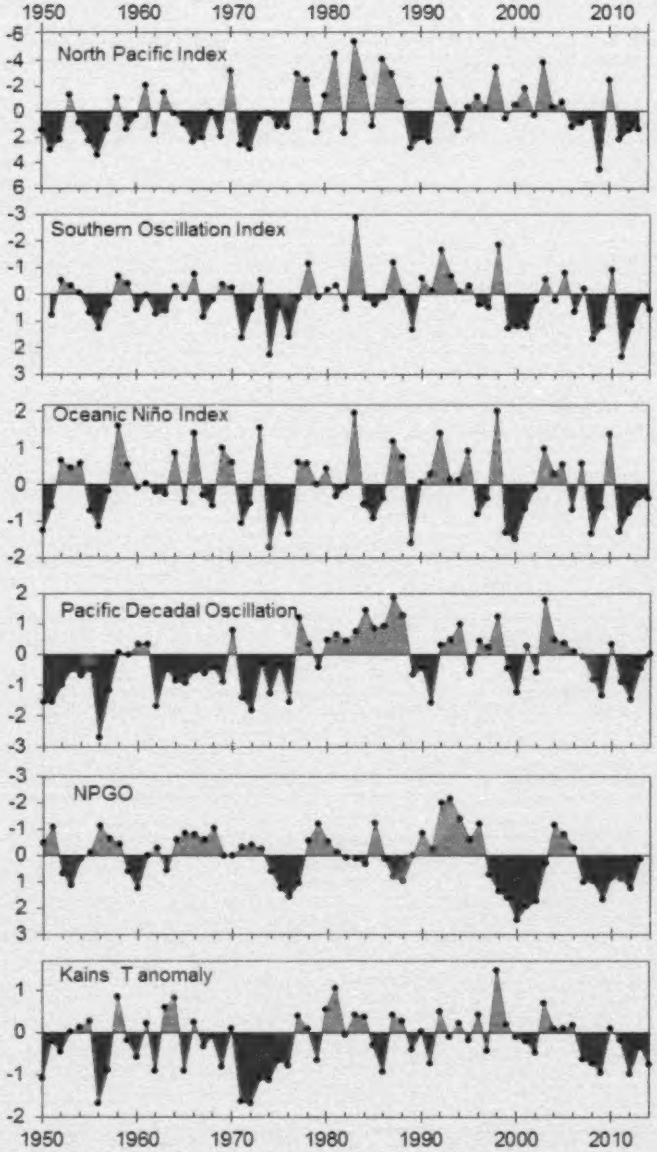

Figure 4.4. Five indices of Pacific Ocean climate in plus temperature anomaly (°C) at Kains Island. Each data point is an average over the months of November to March, and plotted for the calendar year of March. For example, an average of November 2011 to March 2012 is plotted as a data point for 2012. Three of the time series are inverted so their variability is in phase with other series. Indices for 2014 are for Nov. 2013 to Feb. 2014. Two indices, NPGO and North Pacific Index, are not yet available for 2014.

Time series of Pacific Ocean Indices

The panels of Fig. 4.3 reveal SST patterns since September 2011 only. To show longer-period changes in ocean temperature and weather patterns, it is better to present time series of climate indices. Fig. 4.4 presents five climate indices for years since 1950, as well at ocean temperature at Kains Island on the northwest coast of Vancouver Island. Indices are computed for winter months of November to March, partly to allow the most recent observations to appear, and also because winter months tend to be the time of greatest ocean response to El Niño and La Niña events. In general, blue for each index tends to align with cool ocean temperature at Kains Island and red with warm ocean temperature.

It is remarkable how all of the series of Fig. 4.4 are mainly blue over most of the past seven winters. Even in 2013 when warm SST appeared along the west coast in late summer, ocean temperature the following winter at Kains Island was still cooler than average. For the years 2007 to 2014, only the winter of 2010 stands out as red in some graphs.

The time series at top of Fig. 4.4 is the Southern Oscillation Index (SOI), which indicates the strength of the trade winds in the tropical Pacific Ocean, which in turn sets up ENSO episodes. For example, a positive SOI in 2012 (blue in Fig. 4.4) coincided with stronger trade winds, which brought cooler waters to the mid-Pacific Equator and La Niña (positive Oceanic Niño Index in Fig. 4.4). Stronger trade winds coincided with stronger westerly winds in the North Pacific Ocean, which created cooler waters in the eastern Gulf of Alaska and along the west coast of Canada and USA (negative anomaly at Kains Island on the NW coast of Vancouver Island, Fig. 4.4). All these graphs are coloured blue in 2012.

The time series in Fig. 4.4 are explained in the next paragraphs. In general, blue regions prevailed prior to 1977, and red regions after then for about two decades until 1998. The Pacific Decadal Oscillation (PDO) shows this pattern best. An exception is the North Pacific Index (NPI) which remained negative (red) through most years from late 1970s through to the mid 2000s. In general, cooling aligns with La Niña (negative ONI), negative PDO, NPGO and NPI, and positive SOI. Details of these time series are presented next.

Kains Island temperature anomaly time series is based ocean surface temperature measured daily at the Kains Island Lighthouse since 1935 on the southwest coast of Vancouver Island. Base years are 1981 to 2010. Monthly values are provided by Fisheries & Oceans Canada: http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/index-eng.html

Oceanic Niño Index (ONI) is a measure of the anomaly of ocean surface temperature in the central tropical Pacific Ocean, and serves as the official index of the occurrence of El Niño and La Niña episodes as determined by the NOAA Climate Prediction Center. Although it is computed monthly, each value is based on a three-month period centred over the nominal month. The reference period for computing anomalies is 30 years and is updated every five years. A side effect of this particular reference-year system is to suppress climate change and some decadal variability in temperature. ONI is provided by the NOAA/ National Weather Service National Centers for Environmental Prediction Climate Prediction Center: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/detrend.nino34.ascii.txt

Southern Oscillation Index represents the atmospheric sea surface pressure difference between the island of Tahiti and Darwin, Australia, which usually sets up the El Niño and La Niña ocean responses. A strong positive pressure difference is associated with stronger trade winds and positive SOI (blue in Fig. 4.4), and generally sets up La Niña. Negative pressure difference is associated with weaker trade winds, or even a reversal of wind direction in the tropical Pacific, and negative SOI (red in Fig. 4.4), and generally sets up El Niño. SOI is available at: http://www.cpc.ncep.noaa.gov/data/indices/soi.

North Pacific Index (NPI) is the area-weighted sea level pressure over the North Pacific Ocean from 30°N to 65°N and 160°E to140°W. It serves as an index of the impact of ENSO over the North Pacific Ocean. This index is a useful indicator of the intensity and areal extent of the Aleutian Low Pressure system. The NPI was generally negative from 1950 to 1976, and generally positive from 1977 to 2005. This change is attributed to strengthening of the Aleutian Low Pressure system in winter. Since 2005 it has been negative, due to weaker Aleutian Lows. Monthly time series of this index are provided by the Climate Analysis Section, NCAR, Boulder, https://climatedataguide.ucar.edu/climate-data/north-pacific-np-index-trenberth-and-hurrell-monthly-and-winter based on Trenberth and Hurrell (1994) and Wallace and Gutzler (1981). Both monthly and winter-only values are available.

Pacific Decadal Oscillation (PDO) is based on analysis of Mantua et al. (1997) and Zhang et al. (1997). It is the first mode of ocean surface temperature variability in the North Pacific Ocean, and is often positive in El Niño years. However, its variability is slower than that of Oceanic Niño Index, and it is usually a good indicator of temperature patterns that persist for a decade or more. Prior to calculating the first mode of SST variability, the global average temperature for each month is subtracted from the SST at each data location in the North Pacific Ocean. As a result, the PDO time series does not include global warming (or cooling), and instead represents variability and change local to the North Pacific Ocean. The time series is provided at this Internet site of the Joint Institute for Studies of Atmosphere and Ocean of NOAA in Seattle: http://jisao.washington.edu/pdo/PDO.latest

North Pacific Gyre Oscillation (NPGO) is a climate pattern that emerges as the second dominant mode of sea surface height variability in the Northeast Pacific Ocean (Di Lorenzo et al; 2008, 2009). The NPGO mode closely tracks the second mode of North Pacific SST, also referred to as the Victoria Mode. When positive (the blue intervals in Fig. 4.4), the westerly winds over the eastern North Pacific are often stronger than normal and the west coast and eastern Gulf of Alaska are cool. These conditions have dominated in most winters since 1999. The time series is available at this Internet site: http://www.o3d.org/npgo/

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5. 2013 and early 2014 conditions along Line P

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Line P is a series of oceanographic stations extending from the mouth of the Juan de Fuca Strait, south of Vancouver Island, to Ocean Station Papa at 50°N 145°W, in the Pacific Ocean. (Fig. 5.1). The Line P time series is one of the longest oceanographic time series in the world, with data going back to 1956. Fisheries and Oceans Canada visits Line P three times per year, usually in February, June, and August.

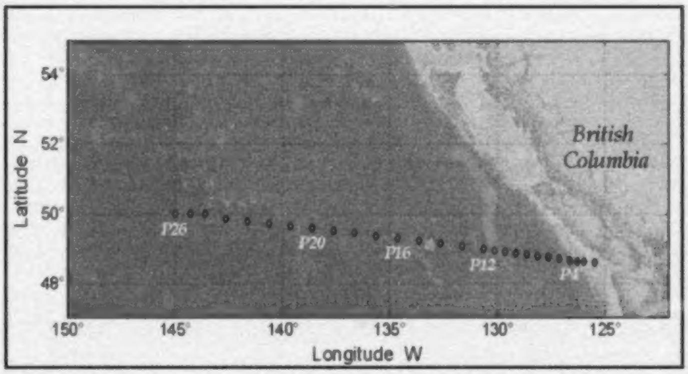

Figure 5.1. Line P and Station Papa (P26).

When looking at temperature anomalies with respect to the 1956 – 1991 average, one can see that the year 2013 started in a rather "normal" way. No important signal could be detected in February 2013 (Fig. 5.2a). In June (Fig. 5.2b) the main signal was a slight warming about 500 km (P14) along Line P centered at 200 m depth, corresponding to an eddy in the area (Fig. 5.3a). By August the eddy had moved westward to ~138°W as well as slightly north (Fig. 5.3b), but the signal is still visible in depth along Line P (around stations P18-P19, Fig. 5.3c). The main feature for August though is the important warm anomaly at the surface. It is really shallow but quite significant. It could be related to the absence of strong winds during the summer, as was the case at Station Papa between the June and August cruise (Fig. 5.4). Finally in February 2014 the major feature is the rather large temperature anomaly going quite deep in the water column (Fig. 5.2d), as discussed by Freeland (this volume).

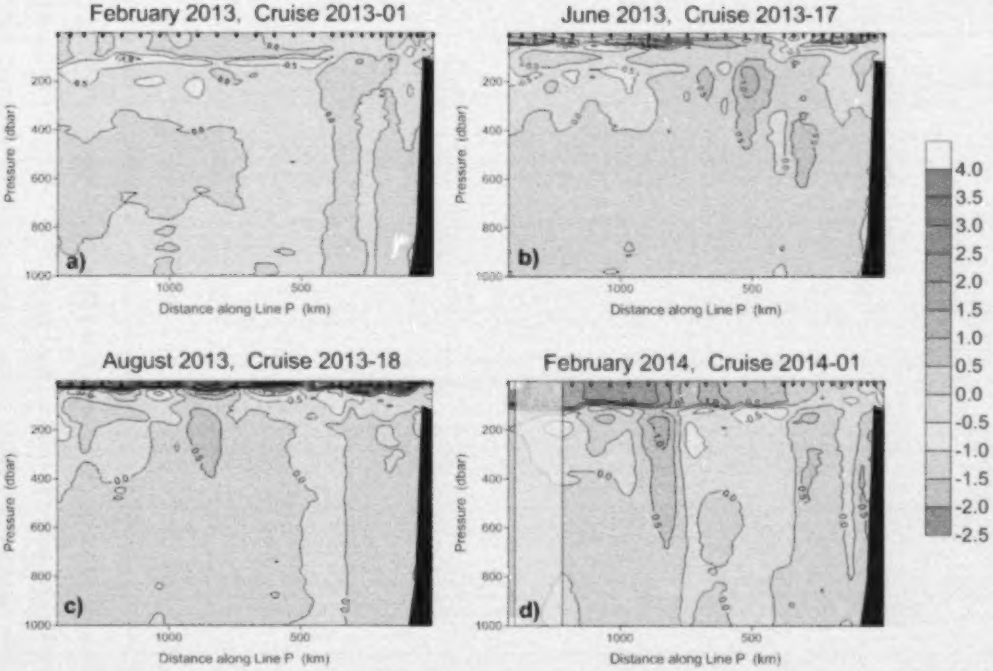

Figure 5.2: Temperature anomaly with respect to the 1956-1991 average. Note that the February 2014 data are not processed.

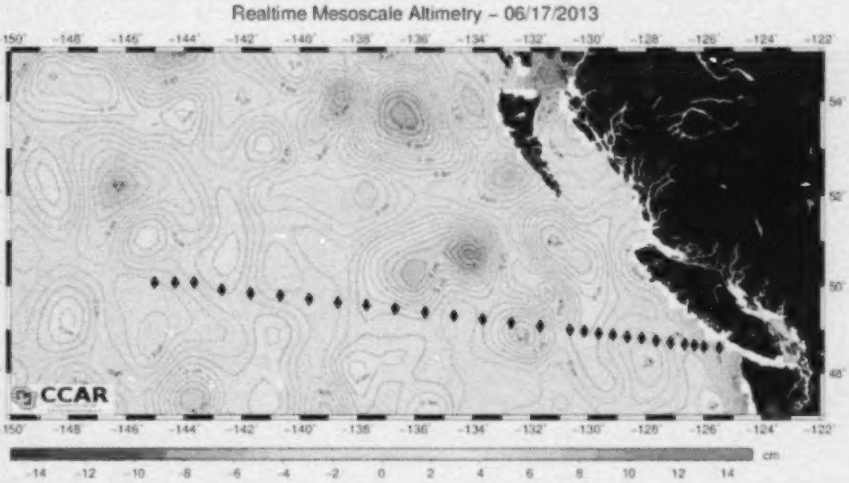

Figure 5.3a. Altimetry in the north east Pacific on 17 June 2013. A small eddy is centered between Stations P13 and P14. The altimetry images were obtained from the Colorado Center for Astrophysics Research.

Realtime Mesoscale Altimetry – 08/27/2013

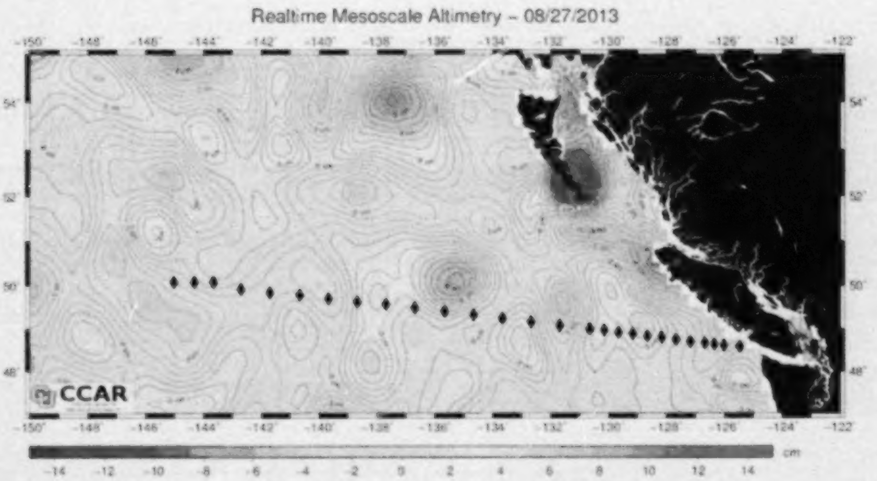

Figure 5.3b. Altimetry in the north east Pacific on 27 August 2013. There is a very small signal around Station P19.

Realtime Mesoscale Altimetry – 02/17/2014

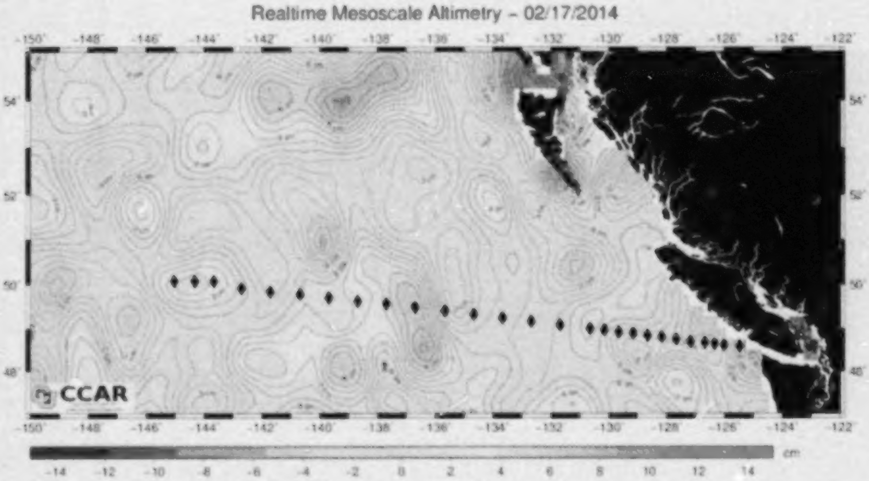

Figure 5.3c. Altimetry in the north east Pacific on 17 February 2014. An eddy can be seen around Station P18.

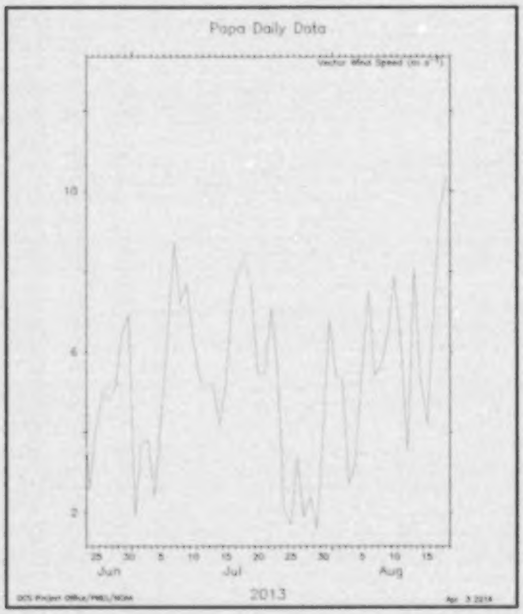

Figure 5.4: Winds at the NOAA Station P mooring between 24 June 2013 and 18 August 2013. The winds were rather calm during the whole summer.

Regarding the salinity signal, the observations along Line P in 2013 and early 2014 reflect what one can see in temperature except for the eddy signatures which are not present in salinity. Each line P cruise salinity anomaly section (with respect to the 1956-1991 averages) can be seen in Fig. 5.5 (February 2013 in a; June 2013 in b; August 2014 in c, February 2014 in d). Again the major feature is shown in the February graph, with a very significant salinity anomaly around Station Papa. Note that the data on this panel (Feb. 2014) are not processed. As can be expected, the temperature and salinity signals are reflected in sigma-t and dissolved oxygen (graphs not shown here).

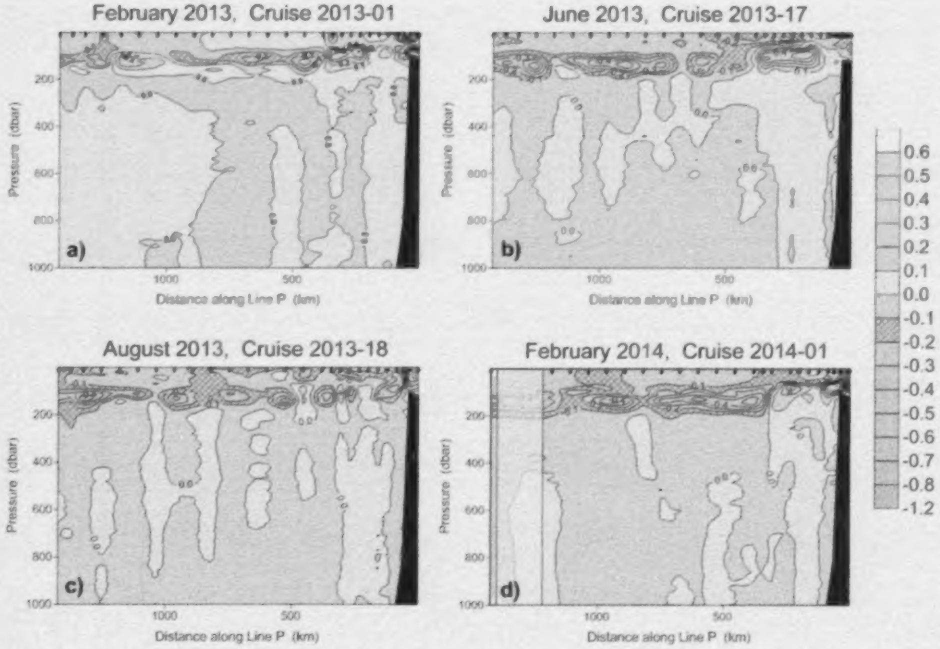

Figure 5.5: Salinity anomaly with respect to the 1956-1991 average. Note that the February 2014 data are not processed.

Freeland, H. 2014. Something odd in the Gulf of Alaska, February 2014. In: R.I. Perry (Ed). State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2013. Can. Tech. Rep. Fish. Aquat. Sci. 3102 (this volume).

6. Something odd in the Gulf of Alaska, February 2014

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Each month I make maps of the surface circulation of the N.E. Pacific. These are computed by reading data at each Argo profile observed during any given month, computing the dynamic height at the surface relative to 1000 dbars and then projecting those dynamic heights onto the first 20 empirical orthogonal functions of the stream function field for the N.E. Pacific computed from a quasi-geostrophic model of the N.E. Pacific that was developed by Patrick Cummins.

It is easy to identify a streamline that I call "the dividing streamline". If the circulation fields remain steady then this is the line that separates water that ultimately flows northwards into the Gulf of Alaska from the water that ultimately flows southwards into the California Current. The latitude of the dividing streamline plotted month by month is shown in Fig. 6.1. It is notable that there was a rapid change in this latitude towards the end of 2012. Though there was a slow recovery of the latitude towards "normal" through 2013, by the end of 2013 it had not yet reached the normal value of 2003 to 2012 (Fig. 6.2)

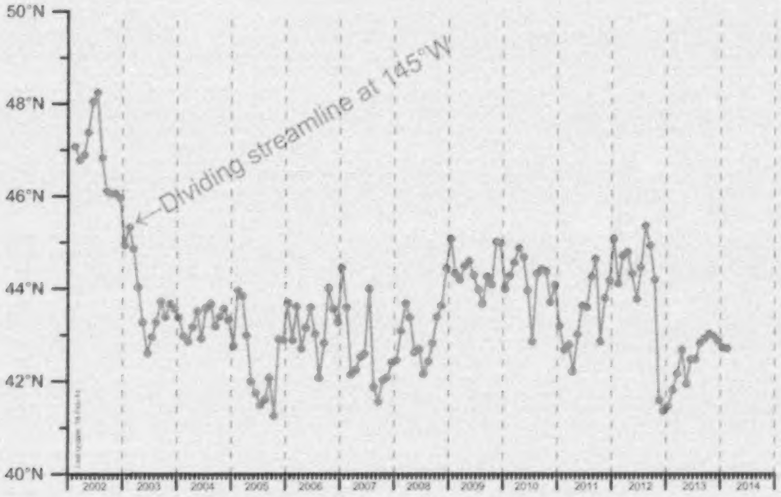

Figure 6.1: The latitude of the dividing streamline versus time.

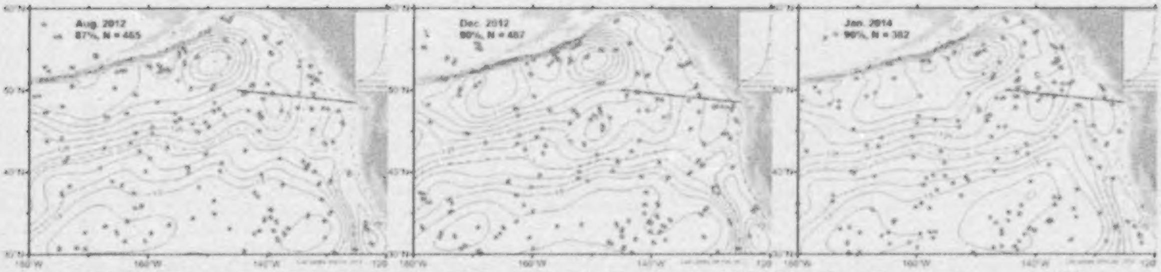

Figure 6.2: Three maps of the circulation of the N.E. Pacific, August 2012 (before the southward shift), Dec. 2012 (after) and Jan. 2014, a recent map.

The southward shift between August and December 2012 is obvious in the maps. It is also clear that the circulation has not recovered as of the beginning of 2014.

There is something very odd going on in the temperature and salinity fields in the N.E. Pacific. Once per month I interpolate Argo observations onto each of the station locations that comprise Line-P, and then compute a Line-P section derived from Argo data. Recent surveys have shown a very rapid influx of anomalously warm and fresh water, apparently arriving from offshore.

In October 2013 temperatures along Line-P were either close to normal or below normal,, as shown by this simulated Line-P section of deviations from "normal" temperature. For "normal" we use a standard climatology computed by Marie Robert some years ago (Fig. 6.3a). By December mild warming was evident offshore and by January the warming was intense (Fig. 6.3b), and the warming continued to grow in February (Fig. 6.3c).

As an independent check that the warming is real and not dependent on a single erratic float; 1) I have checked nearby floats and 4 floats surrounding Station Papa in January 2014, all show this large warming; 2) on the very same day (February 20) that this note is being written a new float (WMOID 4901766) has been deployed at Ocean Station Papa and its first profile gives near-surface temperatures only a few hundredths of a degree Celsius different from the interpolated values and 3) the Reynolds data set that does not include Argo floats shows the same anomaly.

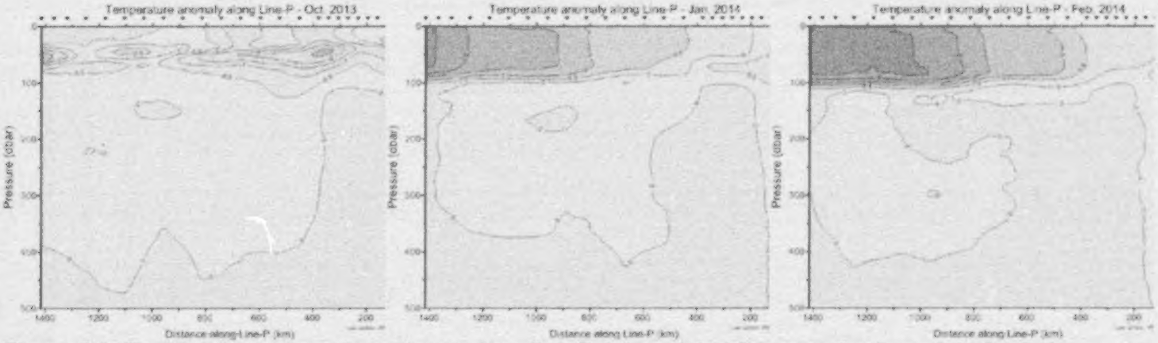

Figure 6.3. Temperature anomaly contours along line P, interpolated from nearby Argo data for Oct. 2013, Jan. and Feb. 2014.

This warm anomaly is enormous. The Reynolds (NCEP) data for the NE Pacific shows a high-temperature anomaly. Fig. 6.4 is computed as the temperature field reported for January 2014 minus the average over all Januaries in the Reynolds dataset (1981-2013, i.e. excluding this anomalous year), divided by the standard deviation. The Reynolds maps are fairly heavily smoothed but show anomalies exceeding 4 standard deviations away from the mean. Four standard deviations away from the mean state is HUGE.

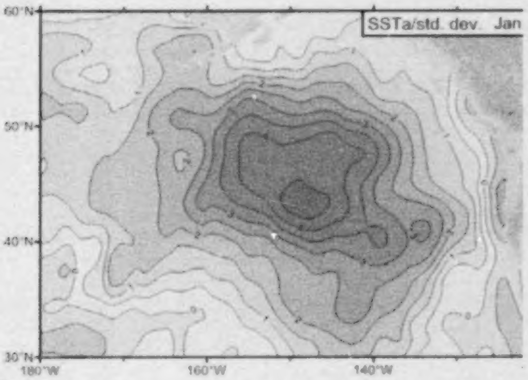

Figure 6.4: Sea surface temperature anomaly in January 2014 normalised by the local standard deviation of temperature.

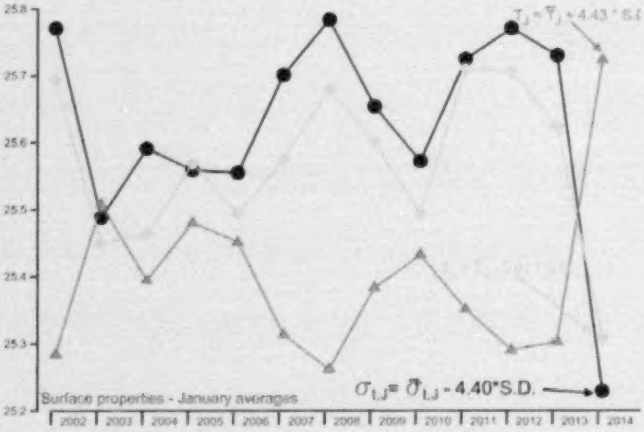

Figure 6.5: Surface properties in January at Station Papa, from 2002 to the present time.

Fig. 6.5 is a plot of surface properties interpolated from Argo floats, temperature (red), salinity (green) and sigma-t (black), averaged over January at Ocean Station Papa for all years for which there is reliable Argo data. This shows little variability, year-to-year, from 2002 to 2013, and then a huge change in properties in January 2014. Again we see huge deviations from normal conditions with temperature in January 2014 4.4 standard deviations above the mean, salinity 3 standard deviations below the mean and as a consequence of both low salinity and high temperature we see extremely low surface density by 4.4 standard deviations. The presence of surface water with anomalously low density must create an energetic barrier to mixing. Further, the Gulf of Alaska appears to have been relatively storm-free during the winter of 2013/14 (we have no objective evidence for that statement, just a gut feeling that there have been few storms). So it should come as no surprise that mixing this winter is very weak.

Fig. 6.6 shows a contour plot of sigma-t at Ocean Station Papa, interpolated from Argo, and contoured versus depth and time.

The annual cycle in Fig. 6.6 is obvious. But look at the deep stratification at the beginning of February 2014, there are 5 black contours between the surface and the first marked coloured contour (just coloured to help a person's eye follow its history). We have never seen such high stratification persisting into the late winter and this must have important effects on the replenishment of nutrients to the surface waters over winter.

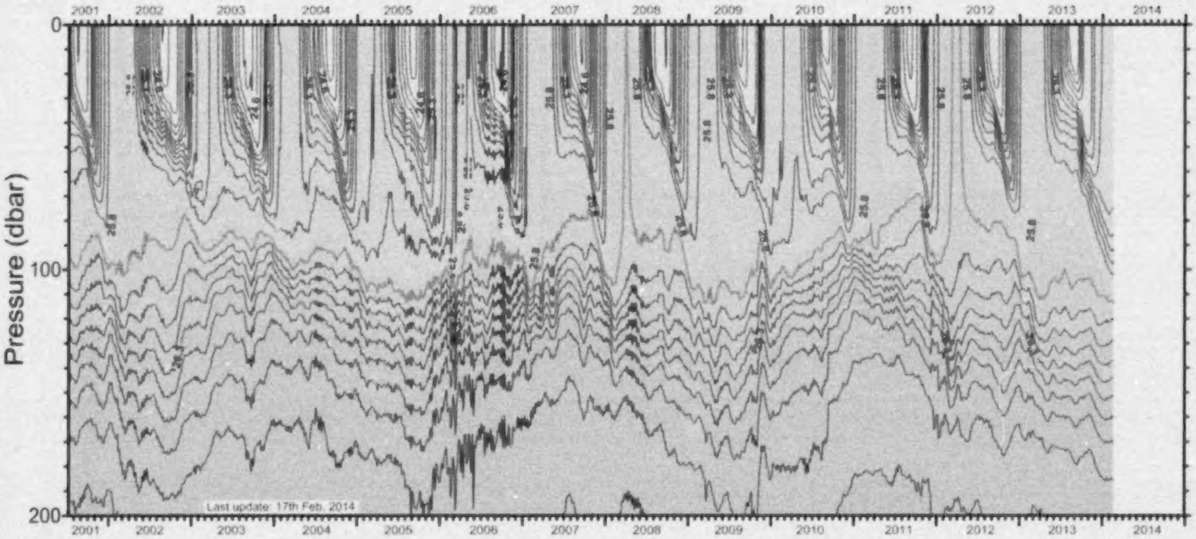

Figure 6.6. Water density (sigma-t; minus 1000 kg m^{3}) at station Papa, interpolated from Argo data.

In summary, the circulation in the N.E. Pacific showed an abrupt change in late 2012 that influenced the circulation throughout 2013. Following that, and possibly associated but we have no clear link at this time, the N.E. Pacific began to demonstrate a gigantic climate anomaly that is leaving us, at the beginning of 2014, with enormous stratification blocking the surface waters from contact with deeper waters. It will be interesting to watch this evolve through 2014 and see some of the ramifications.

7. Long-term trends in weather buoy wind and wave data

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Monthly-average data from the west coast weather buoys show a small apparent long term decrease in wave height, and a small apparent increase in wind speed. Data are available only from about 1988 to the present, so that the observed changes may be due to decadal time-scale variability. Apparent trends in the data have been diminishing as the time series lengthens. At the Middle Nomad location, a longer time series is available back to 1977, but data collected from 1977 to 1988 were from a 10m buoy which caused a definite step in both wind speed and waveheight.

Fig. 7.1 shows the average time series of waveheight for the three offshore (Nomad) buoys. The solid line plot shows the monthly average data with a variable peak waveheight every winter. The dotted line plot shows the result of subtracting a best fit annual cycle based on annual and six-month periods. All three buoys show the decrease at -.0124, -.0098 and -.0085 m/yr of significant waveheight (SWH). Near-shore, exposed buoys showed smaller trends (Fig. 7.2) with values (north to south) of .000, -.001, -.001, -.002, -.008, +.005. The last two trends are from the South Brooks buoy which was installed only in the summer of 1994 and from the La Perouse buoy off Tofino in relatively shallow water.

Fig. 7.3 shows the wind speed time series from the Nomad buoys. Fig. 7.4 shows the data from the six exposed near-shore buoys. The average trend is positive in both cases. Trend values for the three Nomad buoys are .012, .023, .024 m/s/yr. Trend values for the exposed near-shore buoys, north to south, are .015, .020, -.007, .033, -.016, .018 m/s/yr , with four individual buoys showing positive trends, South Brooks with its slightly shorter record showing a negative trend and the South Moresby buoy, also with a shorter record starting summer of 1993, showing a slight negative trend. There is a suggestion in Figs. 7.3 and 7.4 of a step increase in about 1998, which would tend to explain this variation in individual trends.

Wind and waves were low in the winter of 2013. Wind speeds averaged over October 2013 to January 2014 were the second lowest in these months in the 27 years, at 7.86 m/s. The lowest value was in 1993 at 7.66 m/s. Average for the 26 years before 2013 was 8.95 m/s with a standard deviation of 0.44 m/s, so 2013 is 2.46 standard deviations low.

Howard Freeland asked me to look at statistics of wind speed cubed, which measures power, suggesting that power in winter 2013 would be especially low. I find that using cubed wind speeds does not greatly change the picture for 2013, but does increase the significance of the long-term trends. Average wind power of the three Nomad buoys is second lowest in the 27 years, with 1993 slightly lower than 2013. The power average for October 2013 to January 2014 is 2.05 standard deviations lower than the average for the previous 26 years. The r-squared values for rising trends in wind power for the three nomad buoys (north to south) are 0.041, 0.047 and 0.097, compared to 0.012, 0.023 and 0.024 when only wind speed is used.

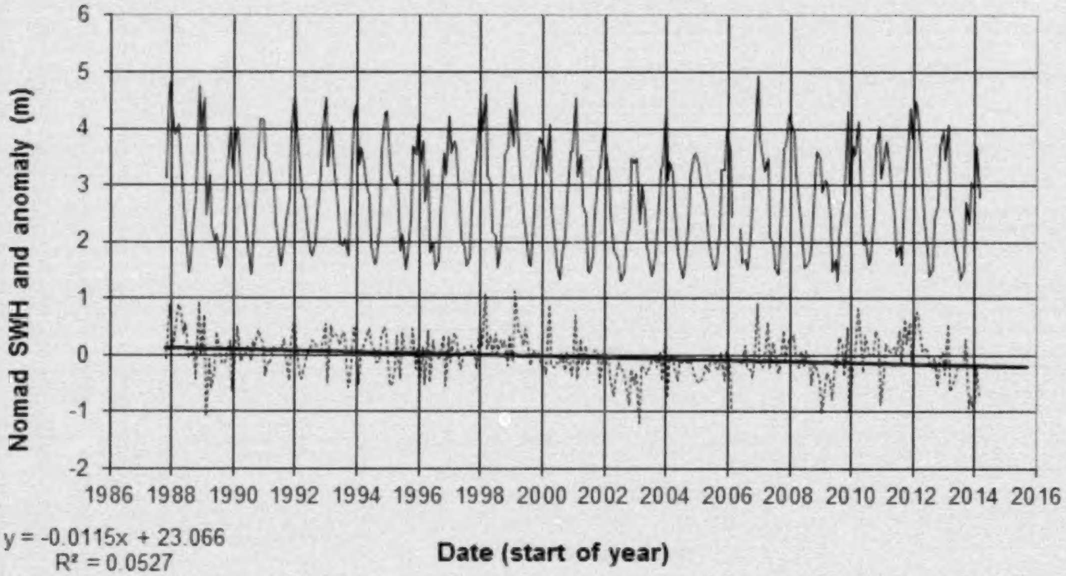

Figure 7.1. Average time series from the three offshore Nomad buoys, showing an apparent decrease in waveheight by about 10% over 26 years ($p=5.10^{-5}$ for independent monthly values, or 0.02 for 3-month correlation).

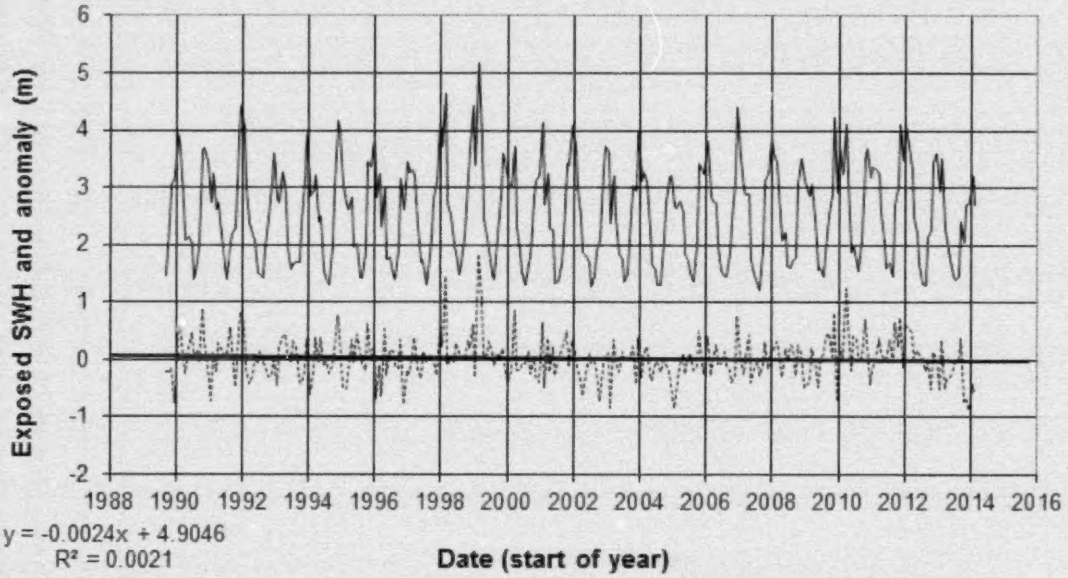

Figure 7.2. Average time series from the six near-shore, but exposed 3-m buoys, showing a very slight apparent decrease in waveheight by about 2% over 26 years (not statistically significant, p=.44 for independent monthly values).

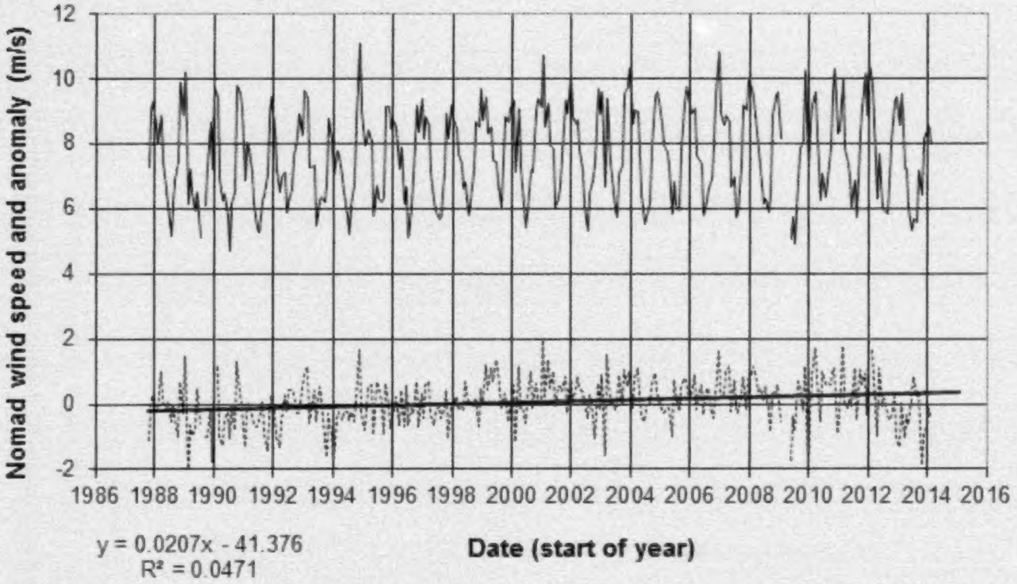

Figure 7.3. Average wind speed time series from the three offshore Nomad buoys, showing an apparent increase by about 2% over 26 years. ($p=1.3.10^{-4}$ for independent monthly values, or 0.028 for 3-month correlation).

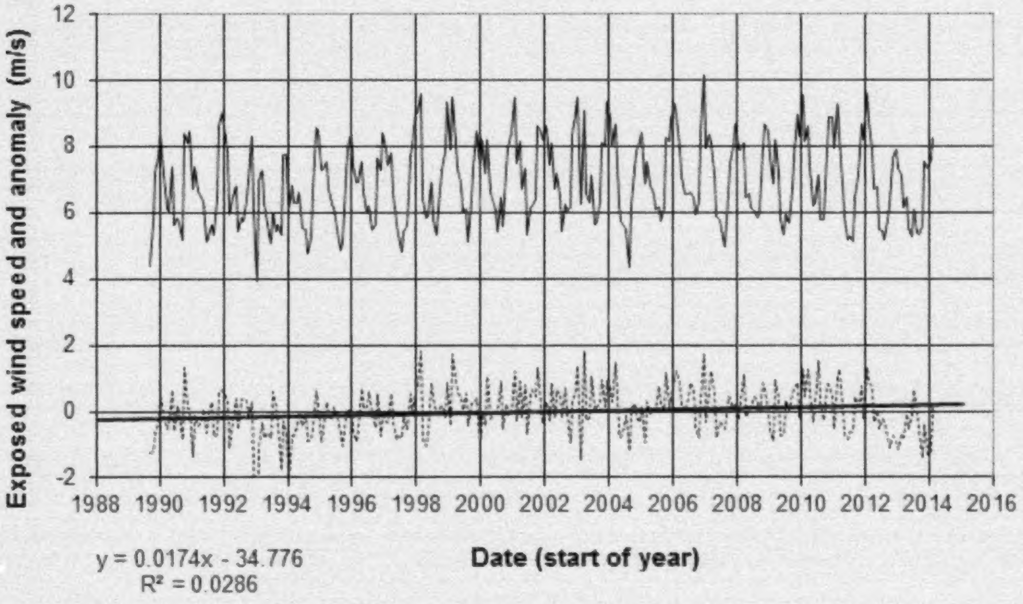

Figure 7.4. Average wind speed time series from the six near-shore, but exposed 3-m buoys, showing an apparent increase by about 2% over 26 years. ($p=4.2.10^{-3}$ for independent monthly values, or 0.10 for 3-month correlation).

8. Satellite and weather buoy sea surface temperatures

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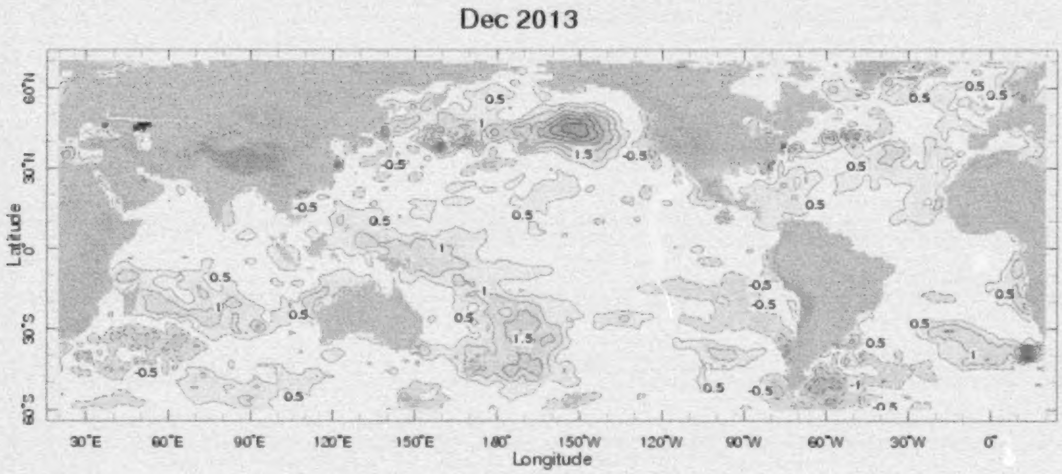
The Reynolds and Smith OISST global sea surface temperature data set available from NCEP shows the Gulf of Alaska to have the largest positive anomaly of any location globally in December 2013 (Fig. 8.1). The anomaly was less marked and further west in October 2013 (Fig. 8.2) and had shifted west with slightly reduced intensity by February 2014 (Fig. 8.3).

Monthly-average data from the west coast weather buoys show a relatively warm late half of the year (Figs. 8.4 and 8.5). Over the longer term, the buoys continue to show slight cooling in data starting in about 1988 (Fig. 8.6).



Dec 2013

Figure 8.1. In December 2013, the Gulf of Alaska showed a strong positive temperature anomaly, centred at 151W, 45N.

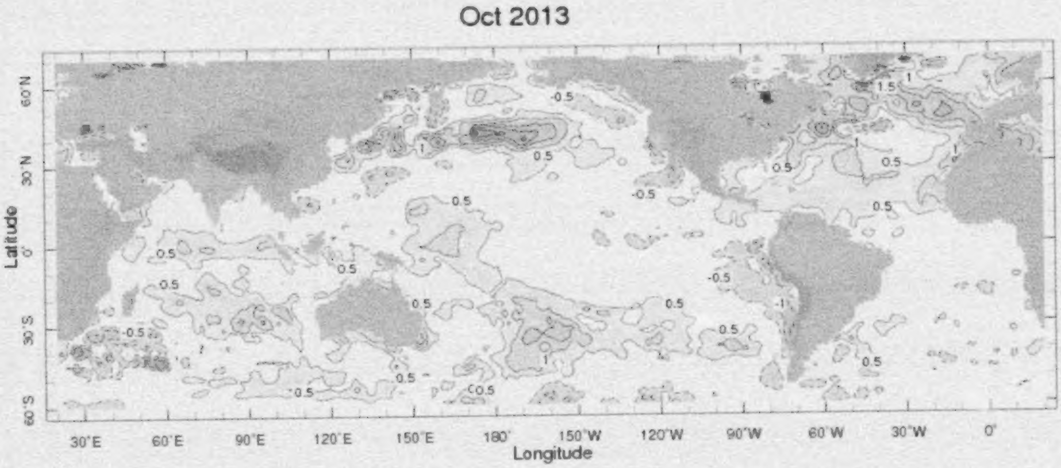

Oct 2013

Figure 8.2. In October 2013 the anomaly was further west and weaker. It was not present earlier in the year.

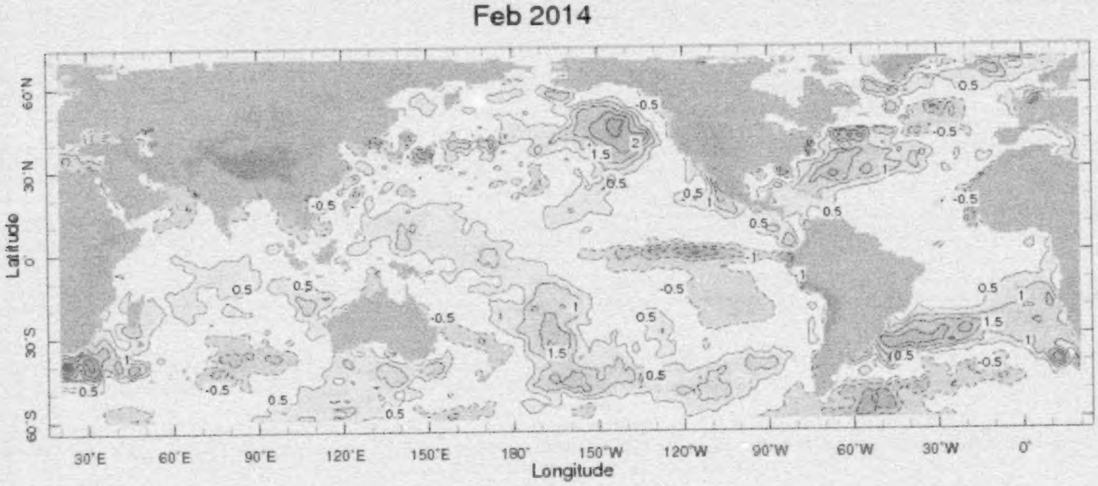

Feb 2014

Figure 8.3. In February 2014, the anomaly is still present, but slightly further east (143W, 46N) and weaker.

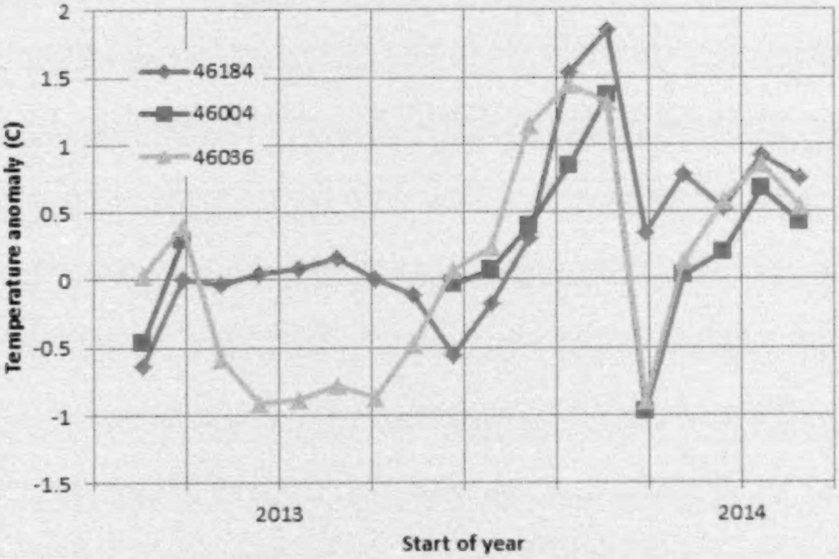


Figure 8.4. The Nomad weather buoys are located on the eastern edge of the anomaly shown in Fig. 8.1. They show a smaller warm anomaly, reaching a maximum of about 1.5 °C in August and September, and only 0.5 °C warm anomaly in December 2013 and February 2014.

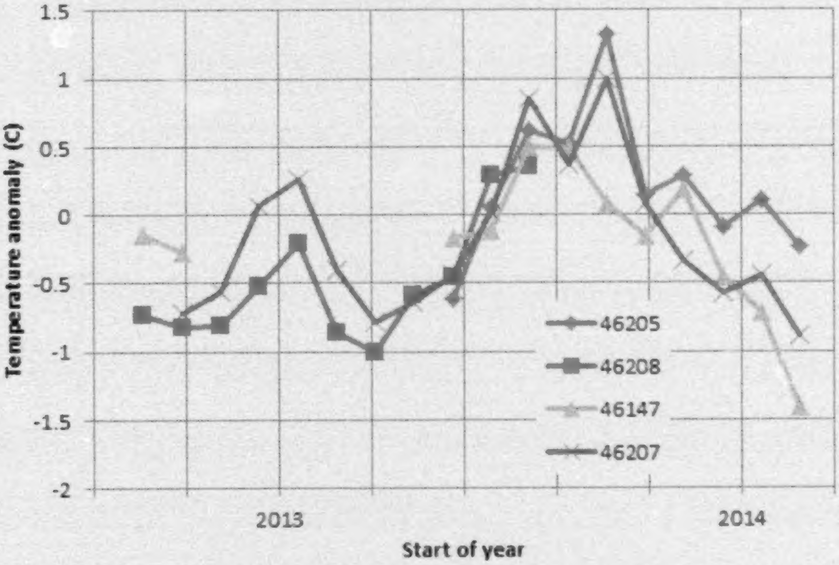


Figure 8.5. Weather buoys along the BC coast show a small warm anomaly, reaching a maximum in August and September, relative to the local cool temperatures indicated by the long-term trend in Fig. 8.6. Temperatures are cooler than average in early 2014.

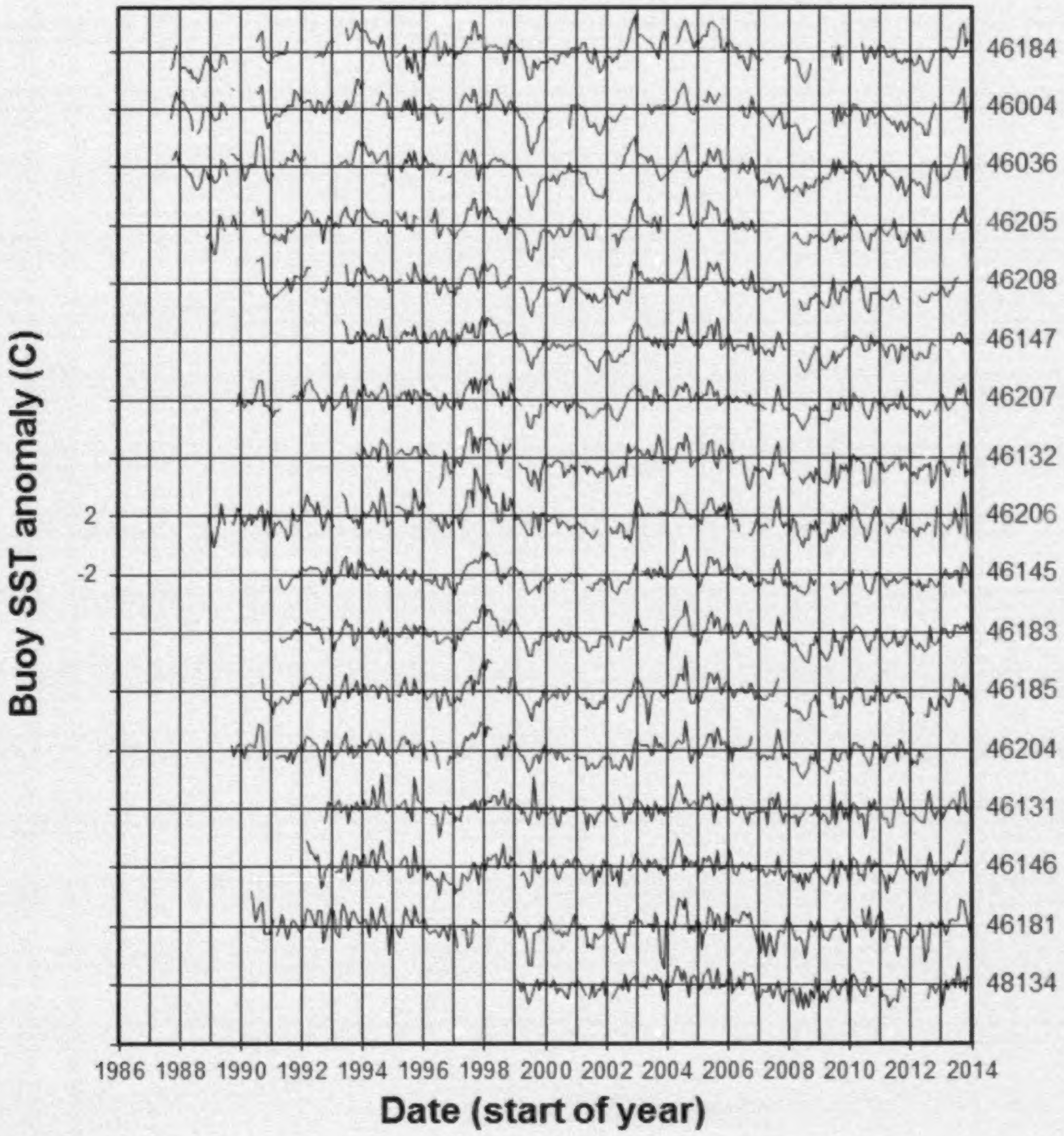


Figure 8.6. With 2013 data added, the west coast buoys continue to show a slight cooling trend since about 1990.

9. Satellite-measured chlorophyll in the Gulf of Alaska and weather buoy sea surface temperatures

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MODIS ocean colour satellite data show average conditions over the southern regions of the Gulf, up to about latitude 54N, but significantly more chlorophyll in July and August over the area 54 to 58N, 139 to 147W. Fig. 9.1 shows the composite image for July 2013. Fig. 9.2 shows the equivalent image for July 2012 with more usual conditions. Fig. 9.3 shows the chlorophyll time series for an area 3 degrees of longitude by 2 degrees of latitude, centred at 145W, 55N. Fig. 9.4 shows the time series for an equivalent area centred on Station Papa (145W, 50N).

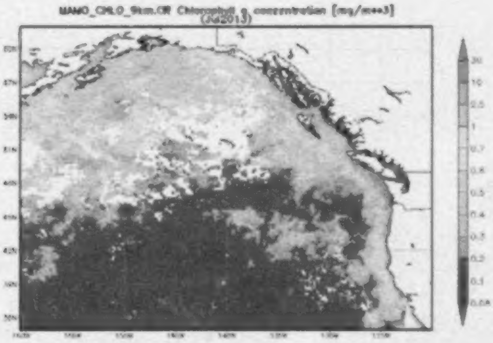

Figure 9.1. Composite chlorophyll image derived from MODIS satellite ocean colour data for July 2013 for the Gulf of Alaska showing an unusual area of relatively high chlorophyll in the northern Gulf.

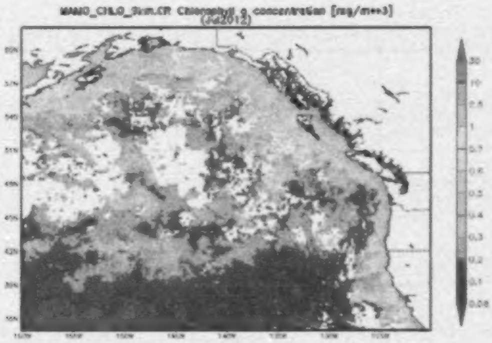

Figure 9.2. Composite chlorophyll image derived from MODIS satellite ocean colour data for July 2012 for the Gulf of Alaska, showing usual conditions in the northern Gulf.

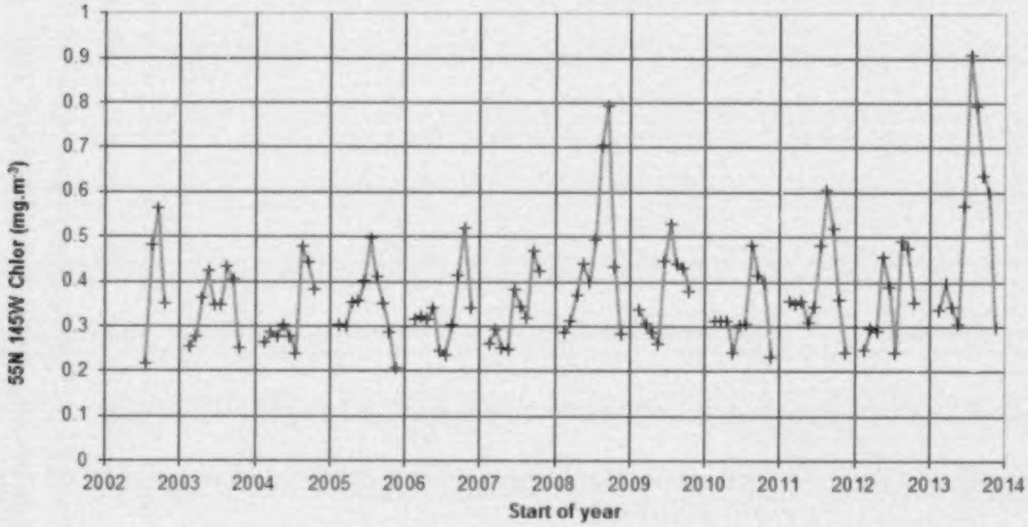

Figure 9.3. Chlorophyll time series derived from MODIS satellite ocean colour data for an area 3 degrees of longitude by 2 degrees of latitude, centred at 145W, 55N, showing the highest value in July 2013 and the peak from the Kasatochi eruption in August 2008.

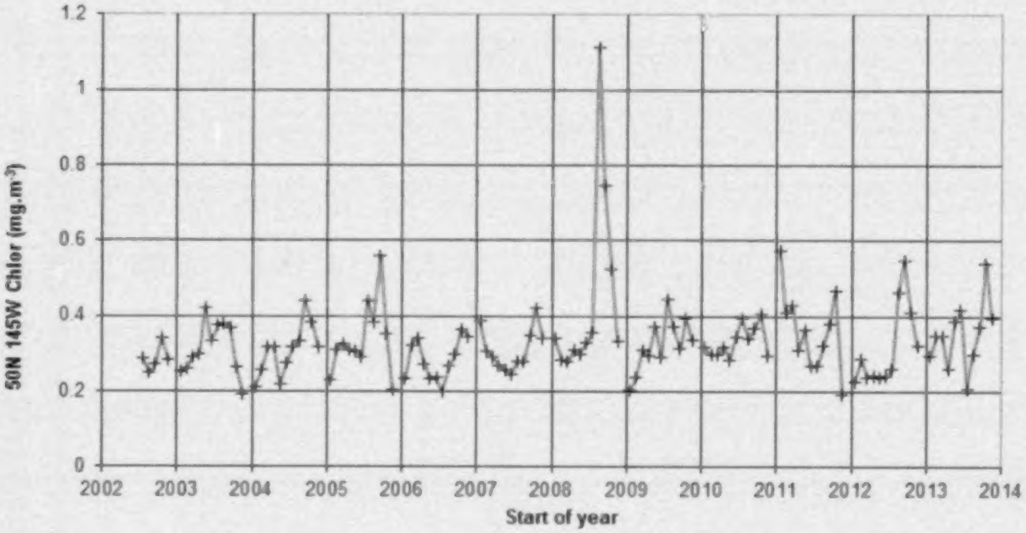

Figure 9.4. Chlorophyll time series derived from MODIS satellite ocean colour data for an area 3 degrees of longitude by 2 degrees of latitude, centred at Station Papa 145W, 50N, showing normal conditions in 2013 and the peak from the Kasatochi eruption in August 2008.

10. Plankton indices from the NE Pacific in 2013

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Sampling from commercial ships towing a Continuous Plankton Recorder occurs approximately monthly 6-9 times per year between March and October in the off-shore NE Pacific (Fig. 10.1). Each CPR sample contains the near-surface (about 7m) plankton from an 18.5 km length of transect, filtered using 270µm mesh, and afterwards analysed microscopically to give taxonomically resolved abundance data. Data to June 2013 have been finalised at the time of writing, while data for July to Sept 2013 are only 25% complete. Several indices are now routinely updated; estimated mesozooplankton biomass, large diatom abundance and a measure of zooplankton community composition.

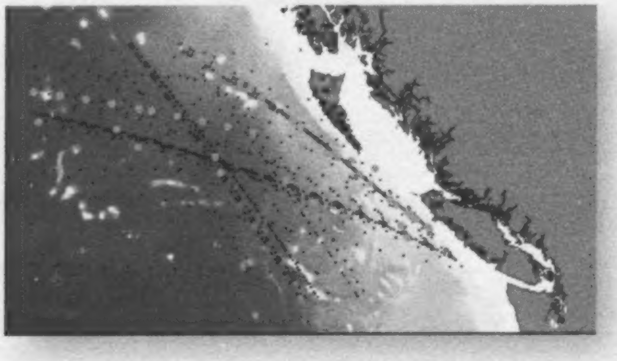

Figure 10.1. Location of historic (black) and 2013 (red) CPR samples used in this report.

Seasonal Cycle

Fig. 10.2 shows the seasonal cycle of large diatoms and mesozooplankton biomass through 2013, compared to the historical data.

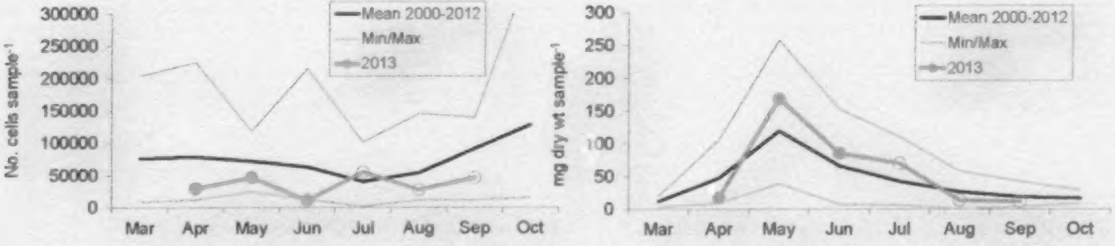

Figure 10.2. Mean monthly abundance of large diatoms (left) and mesozooplankton biomass (right) in 2013. Solid black lines indicate the mean monthly values from 2000-2012, with the grey lines indicating the maximum and minimum monthly value in each case. Filled points are finalised data, open points are provisional values.

Diatoms were generally below average abundance through 2013 while mesozooplankton showed higher than usual biomass through late spring/early summer, though within the range seen before. Annual anomalies are also calculated (2013 compared to whole time series) and as Fig. 10.2 would suggest, diatom anomalies continued to be negative in 2013 (values have been almost entirely negative since 2007, significantly correlated with the PDO index, $p<0.02$), while the zooplankton anomaly was weakly positive.

Zooplankton Timing

By interpolating between sampling dates (better than monthly sampling in the region in Fig. 10.1) we have calculated an index of zooplankton timing, to estimate the day of the year (between day 60 and 300) when 50% of the annual biomass was reached. This is typically earlier in warm years and later in cool years. Fig. 10.3 shows the time series of this index, together with the annual PDO index (correlation between day of year and mean PDO; $r^2= 0.37$, $p<0.02$). The value for 2013 may change slightly when all data are finalised but the season was likely earlier than average.

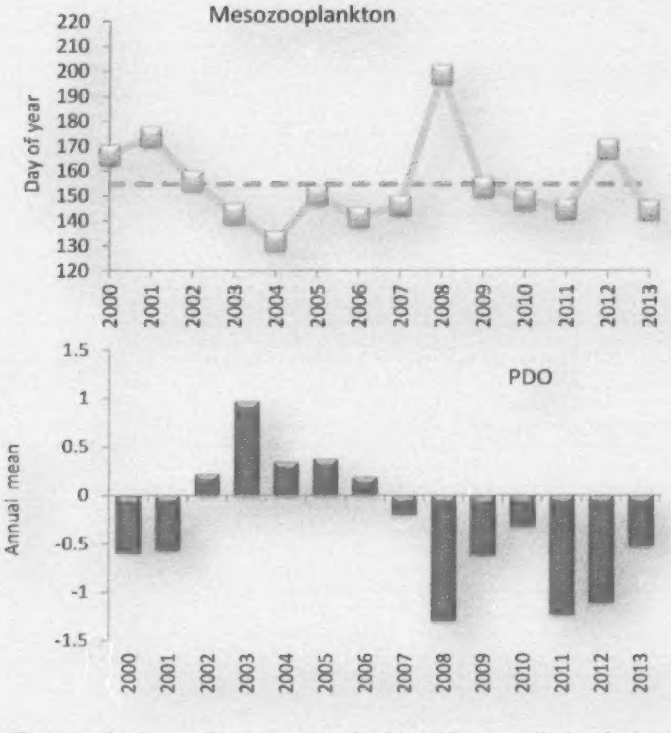

Figure 10.3. Top graph shows the mesozooplankton biomass timing index (day of year when 50% of the biomass is reached) with the long term mean indicated by the dashed line. Lower graph shows the mean annual PDO index (from http://jisao.washington.edu/pdo/PDO.latest)

Zooplankton Community Composition

The zooplankton abundance data for April, May and June each year were combined to examine spring community composition. Fig. 10.4 shows the contribution of major zooplankton groups. In 2013 small copepods made up a relatively small proportion of the community when compared to other years, while euphausiids, large copepods and hyperiids were relatively more important than some other years. Although low in numbers they have high individual biomass, helping to explain the higher than average biomass shown in Fig. 10.2. Note that these data will not change as data to June 2013 have been finalised.

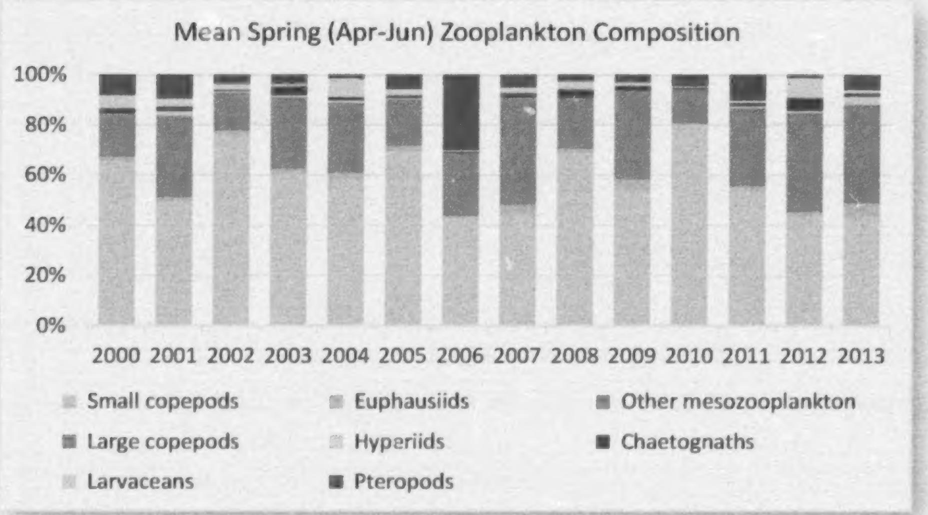

Figure 10.4. Mean contribution (%) to the spring (April, May and June) zooplankton community composition by broad taxonomic groups.

Samples from later in the year, although few in number as yet, showed that warm water copepods were slightly more abundant than in recent years. This is consistent with the anomalously warm conditions in late summer 2013, but until more samples have been completed, it remains speculative.

Summary

CPR data show that in the offshore region large diatoms continued to be lower than average through 2013, while zooplankton biomass was slightly positive overall. There was a bias towards larger zooplankton organisms in spring 2013 and the seasonal cycle was relatively early.

See http://pices.int/projects/tcprsotnp/default.aspx for data and more information.

11. Albacore tuna in BC waters in 2013: A better than average year

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Albacore tuna (*Thunnus alalunga*) is a highly migratory pelagic species widely distributed in tropical and temperate waters of the North Pacific Ocean from the east coast of Japan to the west coast of North America. Two groups of juvenile albacore between the ages of 1 and 5 that undergo large seasonal migratory movements between the central and east and west Pacific Oceans. Some of these juveniles also make trans-Pacific migrations. Albacore in the eastern juvenile group from two to four years of age are the primary target of the Canadian troll fishery along the west coast of North America and in adjacent high seas waters.

Annual variations in the distribution and abundance of albacore in coastal waters are affected by water temperature and food distribution (Alverson 1961; Laurs et al. 1984). Juvenile albacore are attracted to areas of sharp temperature and salinity gradients (fronts) in the transition zone between the subarctic and subtropical gyres in the North Pacific (Laurs and Lynn 1977) and are most commonly caught in water temperatures between 14 and 19°C within the transition area, i.e., "tuna waters", in the eastern Pacific Ocean. Tuna waters and the albacore within them move north and south seasonally and, on average, arrive in the Canadian exclusive economic zone (200 mile limit) beginning in mid to late July and persist through October. Variations in the timing of these seasonal movements affects the availability of albacore in BC waters (Fig. 11.1). Juvenile albacore move into BC waters to forage on small pelagic fishes (e.g., sardine, Pacific herring, saury, mackerel, hake) and squids (Glaser 2010) at the edge of the continental shelf.

Scientists use catch-per-unit-effort (CPUE) or catch-rate (catch divided by the effort to achieve that catch) as a relative measure of fish abundance. Annual CPUEs for albacore in BC coastal waters averaged 66 fish/day during the 2000-2009 period, and the 2013 catch rate was well above average at 79 fish/day (Fig. 11.1). Catch rates in six of the last seven years since 2006 were below average, consistent with cooler La Niña conditions during this period. Albacore catch rates are positively correlated ($r = 0.72$) with July-Oct upwelling index anomalies at 48°N, 125°W, where positive anomalies indicate higher than average upwelling during the summer and fall and negative anomalies are lower than average upwelling for the same period. Above average upwelling supports higher productivity in lower trophic levels on the continental shelf, which in turn enhances albacore foraging opportunities on small pelagic fish and squids at the edge of the continental shelf. Stronger upwelling winds blow from the northwest along the Vancouver Island shelf, and not only upwell more nutrient-rich water near shore, but also push this water and its richer marine life toward the outer edge of the continental shelf, where tuna prefer to feed. This stronger offshore flow of surface waters might also intensify the frontal features offshore of the shelf break, concentrating prey for tuna.

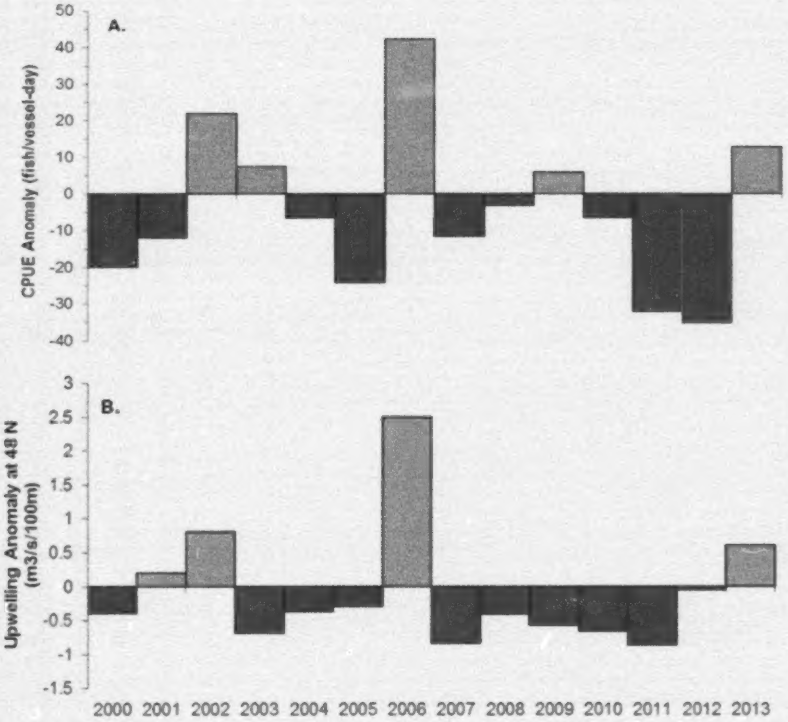

Figure 11.1. Albacore catch rate (fish/day) anomalies in Canadian waters (A top plot) and July-October upwelling index anomalies at 48°N, 125°W (B, lower plot). Zero (0) on both plots is the average for 2000-2009. Anomalies (A) are calculated by subtracting the average from yearly values. Upwelling index anomalies are based on data available at:www.pfeg. noaa.gov.products/PFEL/ modeled/indices/upwelling/ NA/upwell_menu_NA.html.

Albacore CPUE in BC waters was above average in five years of the 14 year time series (positive catch rate anomalies in Fig. 11.1), corresponding to periods when either tuna waters arrived early and persisted for longer than normal in BC waters, or upwelling (and lower trophic level productivity) was above average or both. The largest positive catch rate anomalies in 2002, 2006 and 2013 reflect both higher availability of tuna waters and above average food production as measured by above average upwelling index values. Smaller positive anomalies in 2003 and 2009 seem to occur when tuna water availability is above average, but food production is below average.

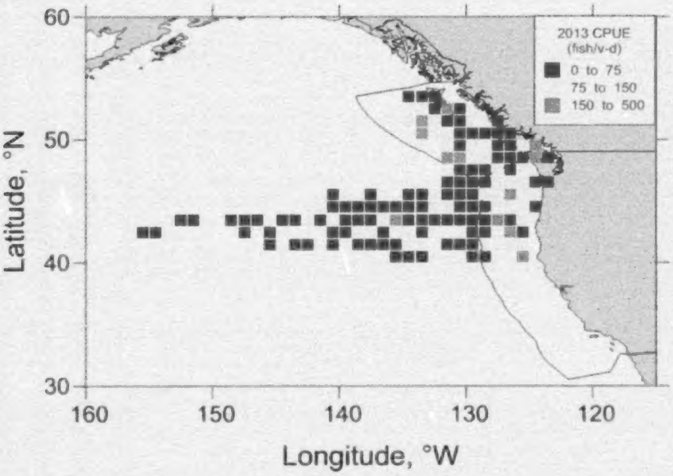

Figure 11.2. Distribution of catch rates (fish/vessel-day) by the Canadian albacore fishery in 2013. Data are plotted for 1° x 1° spatial blocks. Catch rates are estimated as the total number of fish caught within a block from June through October divided by the total number of vessel-days (effort) in that block during the same period.

Tuna waters arrived earlier than normal in late June-early July and persisted to the end of October in 2013. The highest catch rates consistently occurred along the seaward side of the continental shelf as far north as the northern tip of Haida Gwaii and in offshore waters (Fig. 11.2). Total catch of albacore in BC waters was 3,002 t (59% of the fishery), which is a 48% increase relative to the catch in 2012 (2,033 t), although effort in BC waters declined 15% relative to 2012. The increase in catch combined with a decline in effort is consistent with the conclusion that albacore availability was above average in 2013 owing to a larger overlap in time and space between tuna waters (14-19°C) and the continental shelf edge where upwelling dominates productivity and creates foraging opportunities for tuna. Assessments of interannual temporal and spatial variation in albacore distribution and abundance may benefit from considering indices of environmental processes at various spatial scales.

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Laurs, R.M., Fielder, P.C., and Montgomery, D.R. 1984. Albacore tuna catch distributions relative to environmental features observed from satellites. Deep-Sea Res. 31: 1085-1099.

Outer British Columbia Coast

12. Sea level in British Columbia, 1910 to 2013

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The Canadian Hydrographic Service monitors levels along the BC coast. The records below show annual deviations from a long-term average at three ports. Both Tofino and Victoria have records than began in 1910, while the record at Prince Rupert began in 1912.

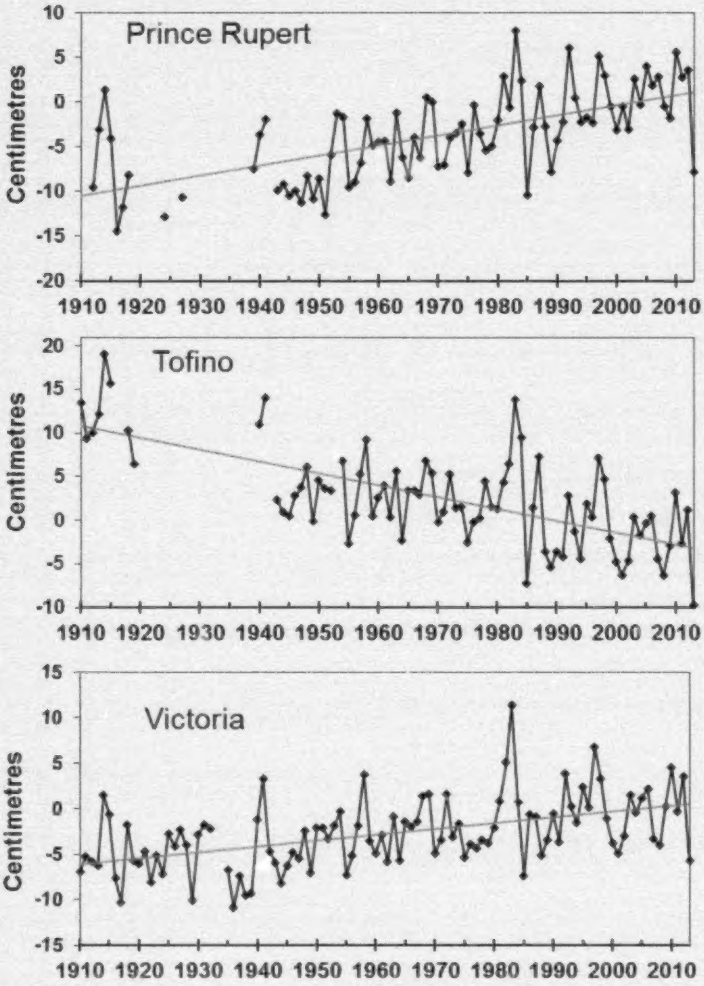

Figure 12.1. Graphs of annual-average sea levels at three British Columbia ports. Reference years are 1981 to 2010. Long-term average linear trends are plotted as red lines.

Average sea level in 2013 was well below the century-long trend at each of the three ports shown in Fig. 1. Sea level was below the 1981-2010 average at all ports in every month of 2013, except in September when unusual winds and very warm waters raised sea level. Although sea level is normally about 15 cm higher in winter than in summer, December 2013 sea level was exceptionally low, due to an atmospheric high pressure system along the British Columbia coast.

The linear trend at each port is listed below (in cm/century):

Prince Rupert	+11
Victoria	+6
Tofino	-14

Tectonic motion is lifting the land at Tofino faster than sea level is rising, so that local sea level is dropping at an average rate of 14 cm per 100 years.

The next Cascadia Subduction Zone earthquake could drop the land at Tofino and along the nearby west side of Vancouver Island by as much as a metre, and also send a major tsunami to the BC coast.

The rate of sea level rise is predicted to be greater in the 21st century. The Intergovernmental Panel on Climate Change (IPCC) in its report released in 2013 anticipates that sea level rise by the end of the 21st century will be in the range of 8 to 16 millimetres per year, which is 80 to 160 centimetres per century, if the increase in greenhouse gas concentration is unabated.

13. Sea surface temperature and salinity trends observed at lighthouses and weather buoys in British Columbia, 2013

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Two sources of data are used to describe changes in sea surface conditions in the coastal waters of BC in 2013. As part of the DFO Shore Station Oceanographic Program sea surface temperature and salinity are measured daily at 12 shore stations at the first daylight high tide at 12 shore stations. Most stations are at lighthouses (Fig. 13.1), with observations taken by lighthouse keepers using thermometers and hydrometers. ODAS (Offshore Data Acquisition Systems) buoys are deployed year-round at the coastal and offshore locations along the West Coasts of Canada. These buoys are designed to collect and transmit hourly sea surface temperature data 24 hours a day, seven days a week.

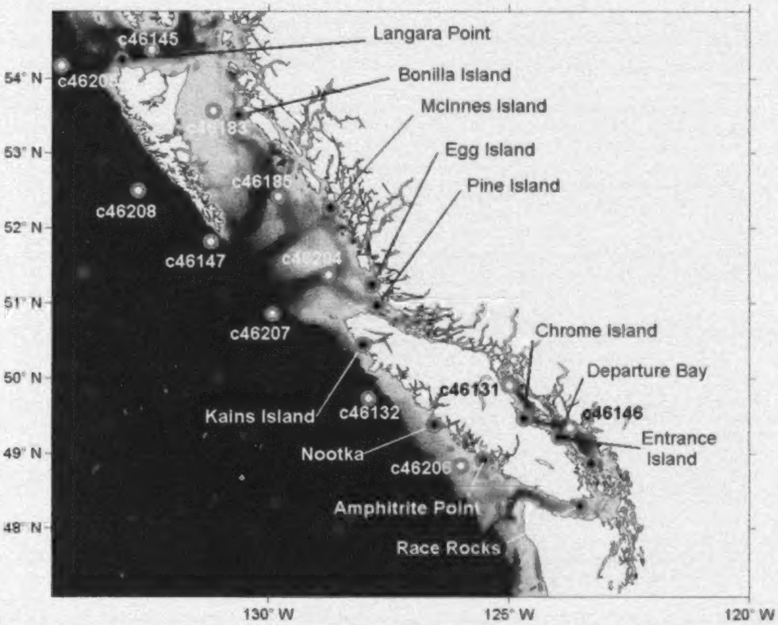

Figure 13.1. Red dots with black centres show the locations of 12 stations in the present shore station network. Red dots with white centers show the locations of 12 weather buoys in the Canadian weather buoy network. See table below for details.

Station	Years of data		Buoy ID	Buoy Location	Years of data
Departure Bay	100		c46146	Halibut Bank	22
Race Rocks	93		c46131	Sentry Shoal	22
Nootka	80		c46206	LaPerouse	26
Amphitrite Point	80		c46132	South Brooks	20
Kains Island	79		c46207	East Delwood	25
Langara	78		c46147	South Moresby	21
Entrance Island	78		c46208	West Moresby	24
Pine Island	77		c46205	West Dixon	24
McInnes	60		c46145	Central Dixon	23
Bonilla	54		c46204	West Sea Otter	25
Chrome Island	53		c46185	South Hecate	23
Egg Island	44		c46183	North Hecate	23

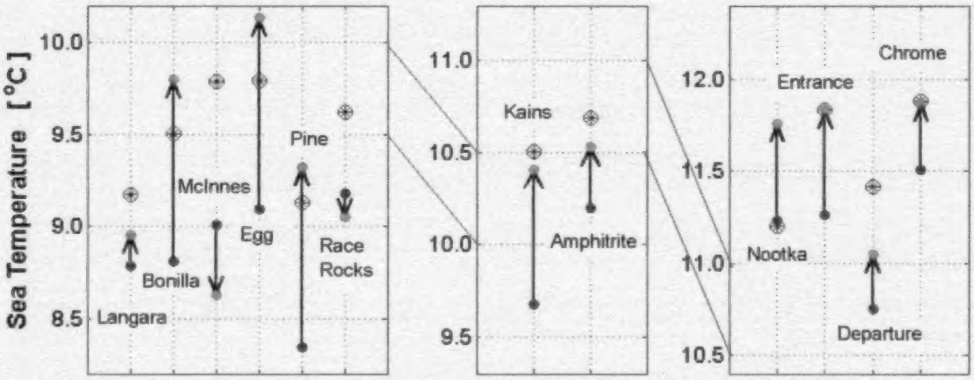

Figure 13.2. The average sea surface temperature in 2012 (blue dots) and 2013 (red dots) from daily observations at shore stations along the West Coast of Canada. Note: the temperature range is the same in each panel, but the temperature values vary; cooler in the left panel and warmer in the right. The crossed circles represent the mean annual temperature based on 30 years of data (1981-2010).

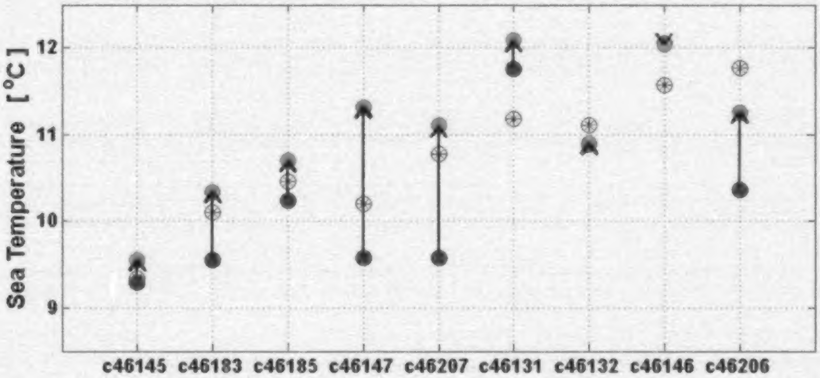

Figure 13.3. The average sea surface temperature in 2012 (blue dots) and 2013 (red dots) from hourly observations at weather buoys along the West Coast of Canada. Note: at three buoys there were insufficient data available to make the comparison between years. The crossed circles represent the mean annual temperature based on all years of data.

The observations at shore stations show the average daily sea surface temperature (Fig. 13.2) was warmer in 2013 than in 2012 at all stations with the exception of Race Rocks and McInnes Island. On average the North and Central Coast stations were 0.55 °C warmer; the West Coast Vancouver Island stations 0.53 °C warmer; and the Strait of Georgia stations 0.41 °C warmer than in the previous year. The average daily SST at all stations (except McInnes, Nootka, and Race Rocks) was closer to the thirty-year average (1981 – 2010) in 2013 than in 2012.

The wave buoy data (Fig. 13.3) show all locations (except c46146, Halibut Bank) were warmer in 2013 than in 2012. The northern and offshore buoys showed a greater increase in temperature (1.0 °C) than the more southerly and inshore buoys (0.34 °C).

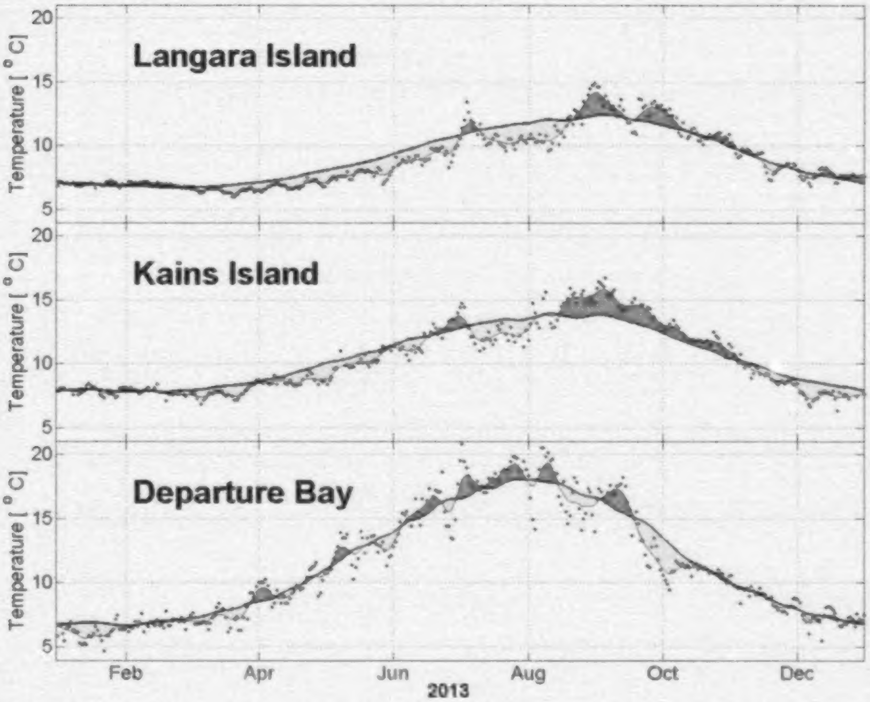

Figure 13.4. Time series of daily SST at stations representing the North and Central Coast, West Coast Vancouver Island and Strait of Georgia. Positive anomalies from the 1981-2010 climatology (7 day low pass rectangular filter) are shown in red, negative anomalies in light blue; the blue dots represent the daily 2013 observations.

The increase in sea surface temperature at the lighthouse stations has variability within the year. As seen in Fig. 13.4 the higher than normal (the 30 year climatology) SST occurred during the summer and early fall, especially at stations on the west coast of Vancouver Island, and at the North and Central coast stations.

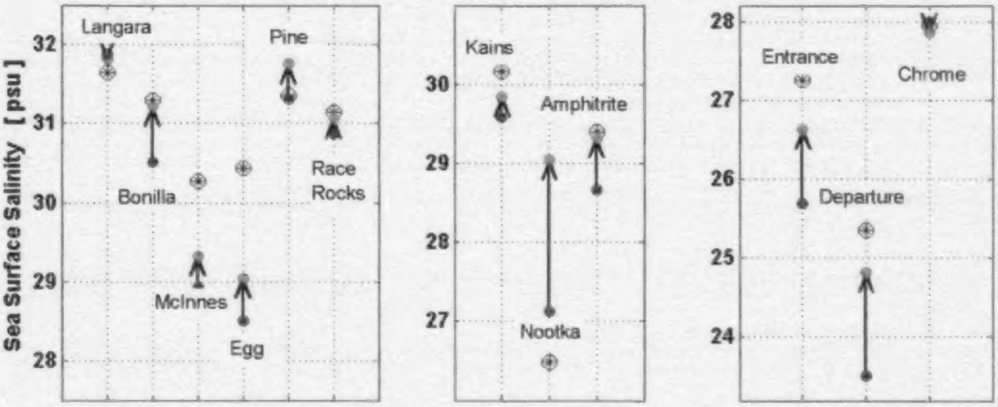

Figure 13.5. The average sea surface salinity in 2012 (blue dots) and 2013 (red dots) from daily observations at shore stations along the West Coast of Canada. Note: the salinity range is the same in each panel, but the salinity values vary; saltier in the left panel and fresher in the right. The crossed circles represent the mean annual salinity based on 30 years of data (1981-2010).

The average daily salinity data attwo locations (Langara and Chrome) freshened slightly, while more saline conditions were observed at all other stations (Fig. 13.5). Over all stations there was a 0.59 psu increase in salinity between 2012 and 2013. The average daily sea surface salinity at all stations (except Pine and Nootka) was closer to the thirty-year average (1981 – 2010) in 2013 than in 2012.

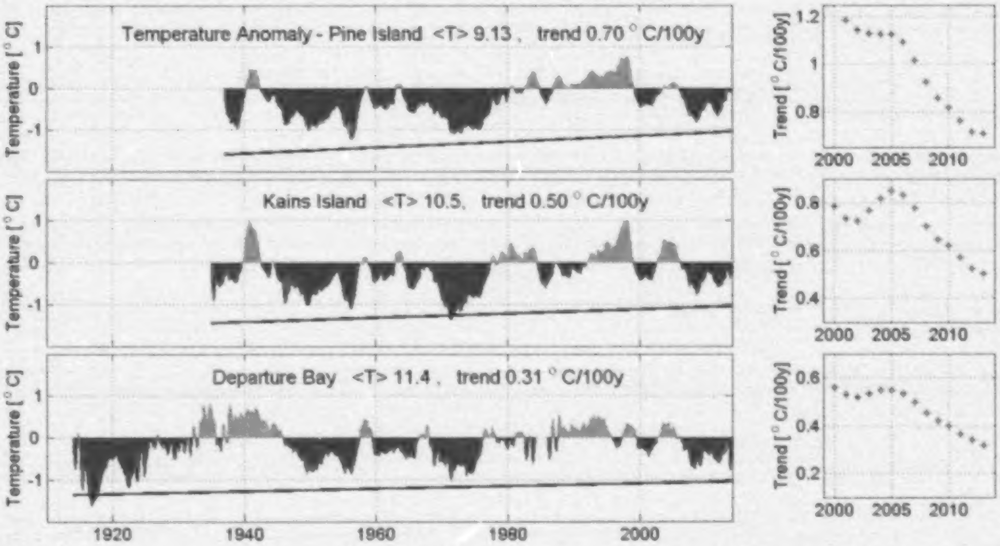

Figure 13.6. Time series of daily temperature observations, averaged over 12 months, at stations representing the North and Central Coast, West Coast Vancouver Island and Strait of Georgia. Positive anomalies from the average temperature of the entire record <T> are shown in red, negative in blue. The panel to the right shows the slope of the trend lines calculated using only data up to the year shown on the x-axis.

Assuming a linear change over the entire data record, the time series of temperature at all of the BC shore stations show a warming trend at a 95% confidence level. Fig. 13.6 shows this warming at representative stations for each of three regions (North and Central Coast, the West Coast Vancouver Island, and the Strait of Georgia). The right panel of Fig. 13.6 shows the SST trend using all data up to the year shown on the x-axis. The slope of the trend varies with time, and while the 2013 conditions were generally warmer than 2012 the influence on the warming trend based on the entire dataset is not sufficient to change the decrease in the long-term warming trend that started in 2005.

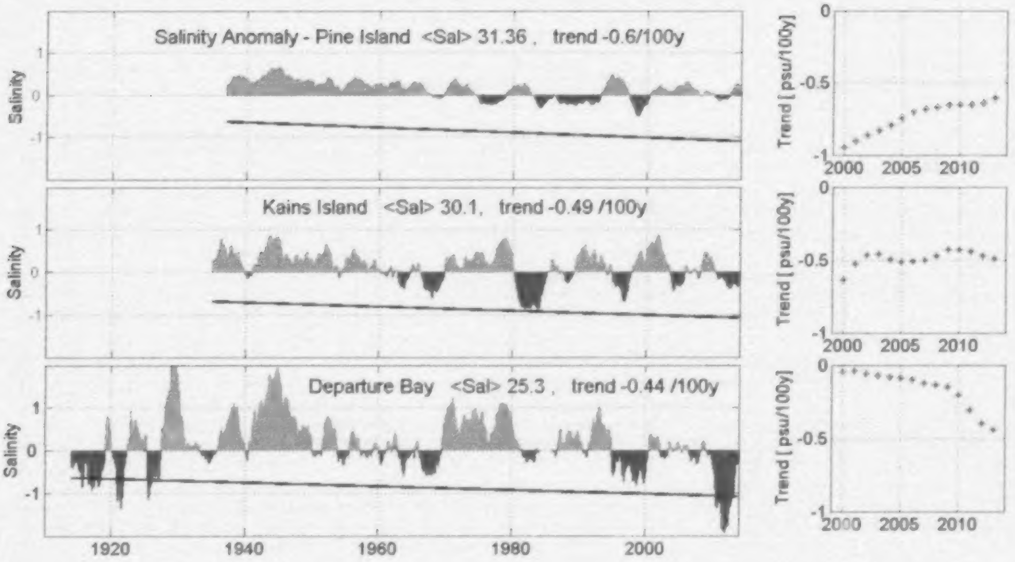

Figure 13.7. Long-term time series of daily salinity observations, averaged over 12 months, for North and Central Coast, West Coast Vancouver Island and Strait of Georgia stations. Positive anomalies from the average salinity of the entire record <Sal> are shown in red, negative in blue. The panel to the right shows the slope of the trend lines calculated using only data up to the year shown on the x-axis.

A similar trend analysis applied to the salinity data (Fig. 13.7) shows a continuing long-term trend toward less saline conditions along the BC Coast, even though 2013 conditions were saltier than last year. Local influences are more prominent in the salinity signal and thus the data are not as representative of the salinity characteristics of the broader region beyond the lighthouse location.

14. Ocean Networks Canada: The 2013 Update from the VENUS and NEPTUNE Observatories

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rdewey@uvic.ca

In 2013, the Ocean Networks Canada (ONC) ocean observatories celebrated eight years of continuous operation from the Saanich Inlet array, six years from the Strait of Georgia array, and over 4 years from the off-shore NEPTUNE array. In addition to the permanent cabled systems, connected to the eight Nodes on the three back-bone cables, the observatory continued to expand with a new shallow coastal observatory at Cambridge Bay, Nunavut. New mobile systems include the acquisition of a Slocum G2 Glider and a permanent Buoy Profiler Station (BPS) in central Saanich Inlet (operational in early 2014). For a complete list of the installations and observing systems, please visit http://www.oceannetworks.ca/.

Shown below (Fig. 14.1) is the complete eight year record of the core time series from 100m depth in Saanich Inlet, including dissolved oxygen, density anomaly (σ_t), salinity, and temperature. 2013 was not a remarkable year, but does have some regional characteristics that are worth noting.

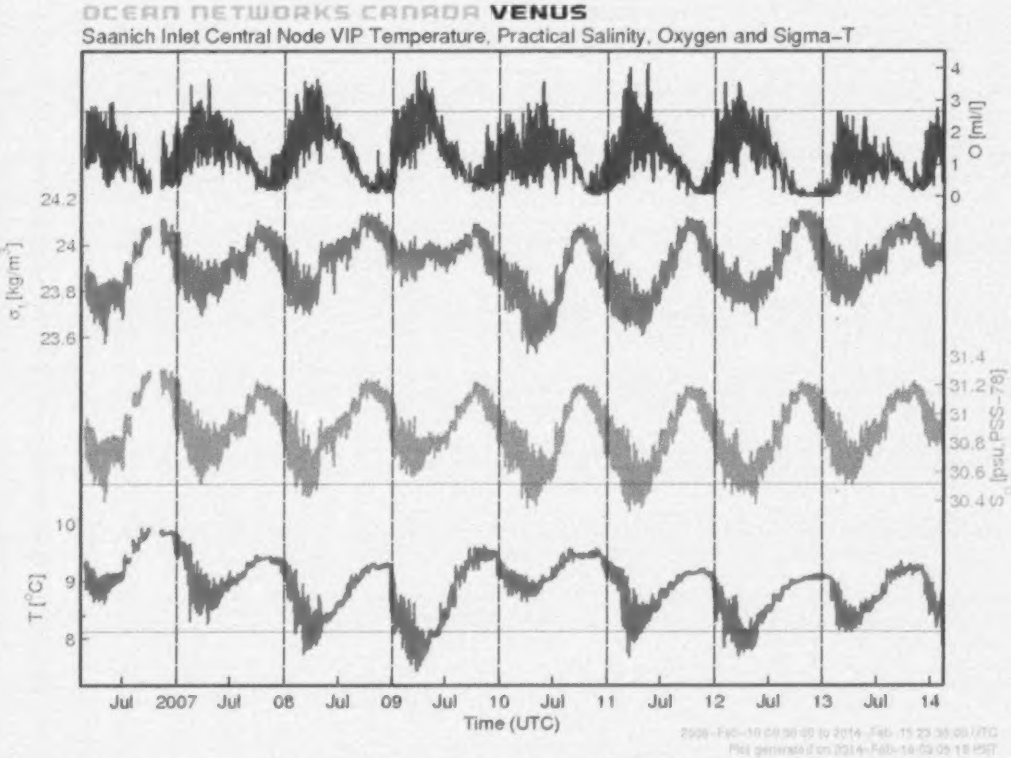
OCEAN NETWORKS CANADA **VENUS**
Saanich Inlet Central Node VIP Temperature, Practical Salinity, Oxygen and Sigma–T

Figure 14.1. Eight year CTD times series from VENUS Saanich Inlet Observatory.

A horizontal line has been drawn at the base of both the temperature and salinity values reached in 2013, and a line at the upper bound reached in dissolved oxygen. The annual cycle of cooling and freshening during the late winter is then followed by the seasonal warming from May through to late October. In 2013 the temperatures at 100m depth did not dip below 8.2°C and the salinity did not dip below 30.5 psu. Oxygen replenishment usually accompanies the cooling (both downward ventilating from the surface, and in 2013 the dissolved oxygen at 100m did not exceed 3.0 ml/l, as it has in all previous years. For the record, the previous warm years were associated with El Nino (2006-07 and 2010), while the mild atmospheric temperatures of the 2013 winter likely led to the reduced ventilation.

Off the west coast of Vancouver Island, the Folger Passage station of the NEPTUNE observatory revealed some interesting characteristics. Shown below (Fig. 14.2) is the CTD time series for Folger Passage.

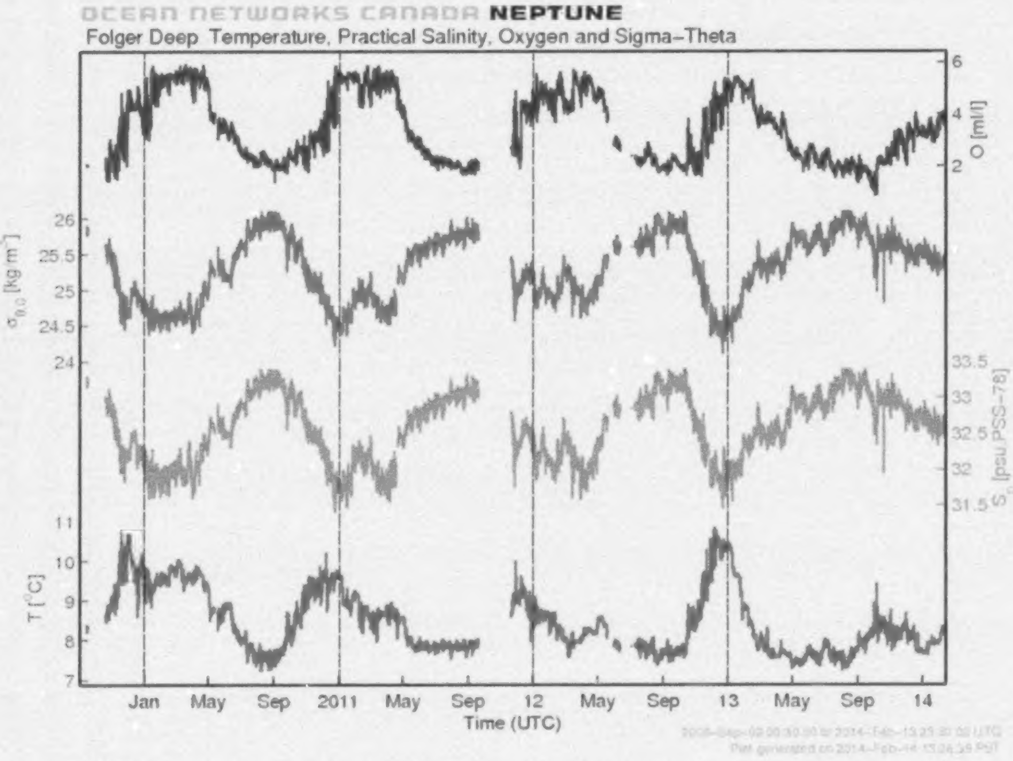

Figure 14.2. Water properties from NEPTUNE's Folger Passage site, at 100m depth at the entrance to Barkley Sound.

Although the record is just over four years long, several seasonal patterns and anomalies are already evident. The typical year (2010-2012) is characterized by fall warming, freshening, and increasing dissolved oxygen (September to December), followed by a late winter period of stability (December to May). The typical onset of upwelling in and about May then causes the temperatures to drop, salinity to rise, and oxygen to decrease. In 2013, the onset of upwelling seems to have occurred very early in the year, with temperatures dropping, salinities increasing and oxygen levels declining in January. This resulted in a prolonged period of low temperatures and higher salinities, rather than peak values, which are usually reached in August. The fall of 2013 was also a little anomalous in that the rise in temperature and drop in salinity associated with downwelling conditions is subdued. By late December 2013 temperatures were still low (8C) and salinities remained above 32.5 psu. These anomalous conditions are mostly tied to the unique character of the upwelling winds in 2013.

Shown below (Fig. 14.3) is a plot of the cumulative upwelling index made available by the NOAA Pacific Fisheries Environmental Laboratory (www.pfeg.noaa.gov) from winds off the southwest coast of Vancouver Island (48N 125W). The winds in 2013 were distinctly different than the season means, which typically includes a downwelling season from early September (day ~255) through to mid-April (day ~100) and an upwelling season (winds from the NW) from late April (day ~110) through early September (day ~250). 2013 is marked by a very weak downwelling season, a moderate upwelling season with a majority of the upwelling occurring in July, followed by weak downwelling. In fact, the net cumulative downwelling from January through to December is only 500 $m^3/s/100m$, compared to the long-term average of 10000! By late fall 2013, the cumulative upwelling index was not only above and outside the long-term standard deviation, it was the weakest annual downwelling season on record. This lack of southerly winds and downwelling conditions explain the slight anomalies in the Folger Passage CTD record.

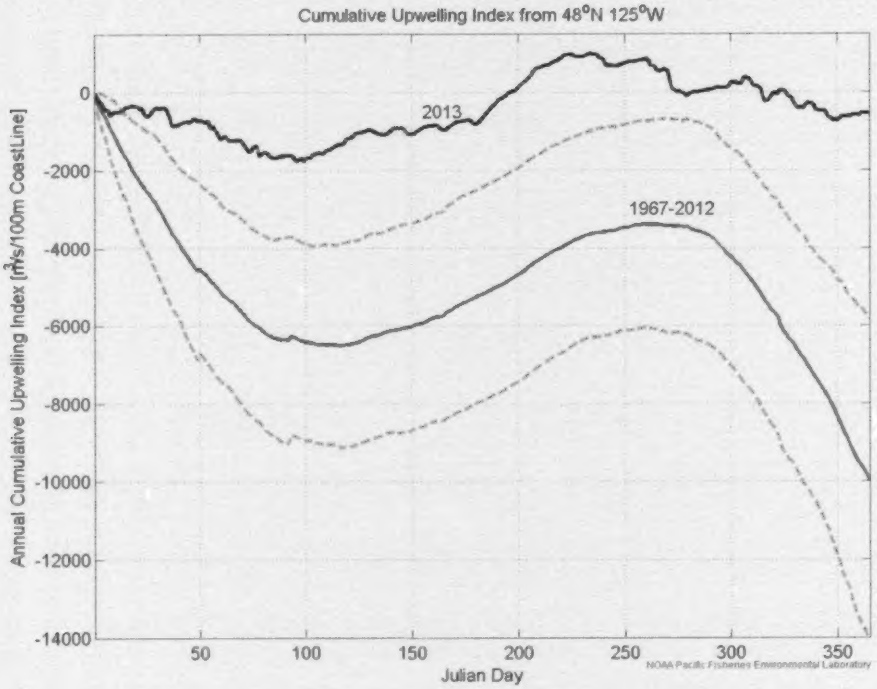

Figure 14.3. Cumulative upwelling index from 48N 125W showing the long term (1967-2012) average and standard deviations, and in black, the index for 2013. Units are cubic metres per second per 100m of coastline. Data from www.pfeg.noaa.gov.

15. Zooplankton along the BC continental margin: a near-average year

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Zooplankton time-series coverage of the British Columbia continental margin extends from 1979 to present for southern Vancouver Island [SVI], from 1990 to present for northern Vancouver Island [NVI] (although with much lower sampling density and taxonomic resolution in 1991 to 1995), and from 1998 to present for southern Hecate Strait (with some scattered earlier sampling between 1983 and 1997). The 'standard' sampling locations in SVI, NVI and Hecate regions are shown in Fig. 15.1. Additional locations are included in averages when they are available. Due to a lack of samples from Hecate Strait for the years 2012 and 2013, there will be no update in this report for that area. Samples are collected during DFO research surveys using vertical net hauls with black bongo nets (0.25 m^2 mouth area, 0.23 mm mesh aperture), from near-bottom to sea surface on the continental shelf and upper slope, and from 250 m to surface at deeper locations. We have also recently compiled historic data from various shorter term sampling programs in the Strait of Georgia [SoG]. Most of the SoG sampling did not follow a standard grid or sampling protocols. Because of time varying taxonomic resolution, the SoG data were merged into broader categories (size classes within major taxa). Our analyses-to-date of the SoG time series are described in Mackas et al. 2013 and the State of the Pacific Ocean 2012 report, but are not updated in the present report.

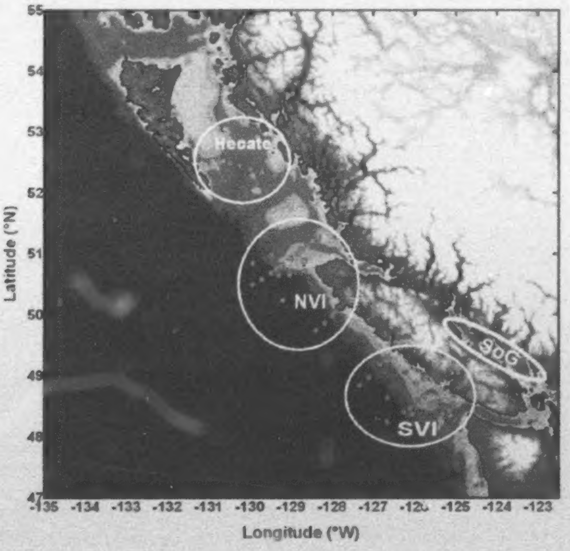

Figure 15.1. Zooplankton time series sampling locations (red dots) in BC marine waters. Data are averaged within major statistical areas indicated by ovals; the SVI and NVI regions are further classified into shelf and offshore subregions. The PNCIMA (Pacific North Coast Integrated Management Area) includes both NVI and Hecate stat areas. Preliminary results from the SoG time series are described in Mackas et al. 2013.

We routinely estimate abundance and biomass for more than 50 zooplankton species in the SVI, NVI, shelf and offshore. For these regions, seasonal variability is intense and somewhat repeatable from year-to-year. However, because sampling dates vary from year to year, simple annual averages of observations confound seasonal with interannual differences. We deal with this by first estimating a multi-year average seasonal cycle (= "climatology") for each region, using the data from the start of each time series through 2008, and then using these climatologies as baselines against which we can then compare monthly conditions during any single year. To describe interannual variability, our approach has been to calculate within each year a regional, logarithmic scale biomass anomaly for each species and for each month that was sampled in a given year. We then average the monthly anomalies in each year to give an annual anomaly (see Mackas 1992 & Mackas et al. 2001 for mathematical details; for SoG see Mackas et al. 2013). It is important to note that the anomalies are log scale and therefore multiplicative on linear scale: an anomaly of +1 for a given taxon means that taxon had 10X higher biomass than in the climatology; an anomaly of -1 means the biomass was 1/10th the climatology.

We have learned from our own and also from other west coast time series (Mackas et al. 2006) that zooplankton species with similar zoogeographic ranges and ecological niches usually have very similar anomaly time series. We therefore often summarize the interannual variability of multiple species by averaging within species groups. For example, the group 'boreal shelf copepods' is a composite of the copepods *Calanus marshallae*, *Pseudocalanus mimus*, and *Acartia longiremis;* all of which have distribution ranges that extend from southern Oregon to the Bering Sea. The group 'subarctic oceanic copepods' is a composite of *Neocalanus plumchrus*, *N. cristatus*, and *Eucalanus bungii*; all of which inhabit deeper areas of the subarctic Pacific and Bering Sea from North America to Asia. A third group, 'southern copepods' is a composite of five species from the genera *Clausocalanus*, *Calocalanus, Mesocalanus* and *Paracalanus* with ranges centered about 1000 kilometers south of our study areas (either in the California Current and/or further offshore in the North Pacific Central Gyre).

Fig. 15.2 shows anomaly time series for these copepod species groups, for representative chaetognaths and euphausiids in each of the BC statistical areas. The range of interannual biomass variability within a species or species group is about one log unit (i.e. factor of 10). This is about 2-3 times greater than the interannual variability of total biomass in our regions. Other features to note are that anomalies often persist for several years and that, in addition to the covariation within species groups mentioned above, there is strong covariation between some species groups. The clearest and most gradually varying signals have been in the three copepod groups and in the chaetognaths. Cool years such as the early 1980s, 1999-2002, and 2007-9 had positive anomalies of boreal shelf and subarctic copepods, and northern chaetognaths. Warm intervals such as 1983, 1993-1998, 2004-2005 and 2010 tended to have negative anomalies of these taxa, but positive anomalies of southern copepods and southern chaetognaths. From previous work, we now know that positive anomalies of the cool water zooplankton community off Vancouver Island are also associated with good local survival and growth of juvenile salmon, sablefish, and planktivorous seabirds (Mackas et al. 2007; M. Trudel, personal communication).

What were the conditions of 2013? The year started off as a cool year in all sub-regions, with strongly positive anomalies for both sub-Arctic and boreal zooplankton. However, in late summer (August and September), warm offshore water with higher abundance of southern zooplankton species moved shoreward. This led to a moderation of the annual anomaly signal in all species groups: what was positive at the beginning of the year was negative or near zero by fall (or vice versa), cancelling or tempering each other to give a yearly signal closer to the long term average. The influence of the summer intrusion off offshore warm water was strongest in the SVI offshore subregion (compare Fig.15.2 with Fig.15.3), but the more northerly (NVI shelf and offshore) and SVI nearshore regions also had a similar but weaker seasonal trend toward southern fauna.

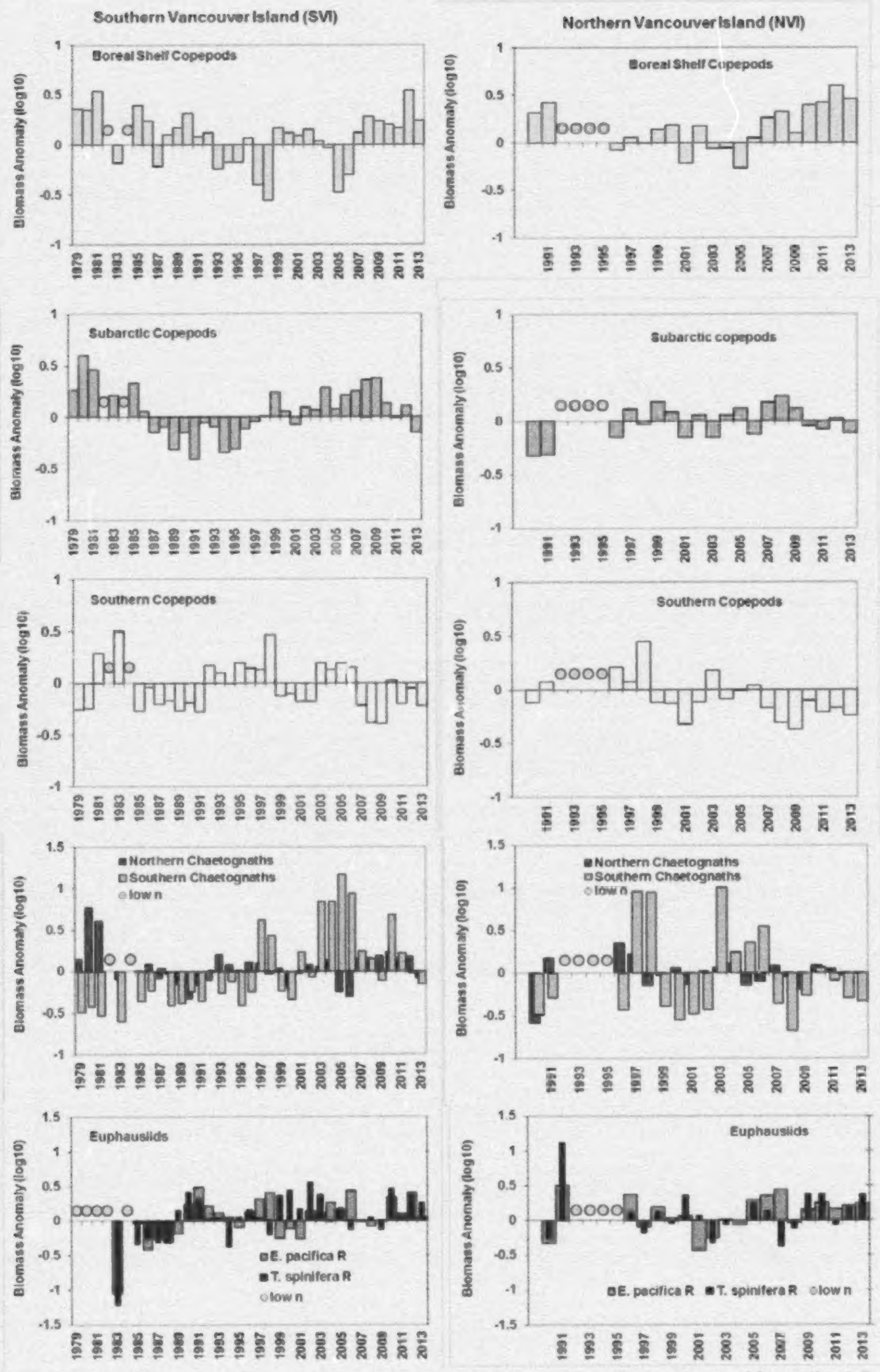

Figure 15.2. Zooplankton species-group anomaly time series (vs climatological baseline) for the SVI (left) and NVI (right) regions shown in Fig. 15.1. Bar graphs are annual log scale anomalies. Circles indicate years with no or very few samples from that region. Cool years favor endemic 'northern' taxa, warm years favor colonization by 'southern' taxa.

Due to this cool to warm transition of sea state, 2013 was overall a near-average year (anomalies neither strongly positive nor strongly negative) off the west coast, except that boreal copepods which continue a trend of fairly positive over the last four to five years. In 2013, boreal copepods fared better on the shelf than in the offshore region of SVI, this is reversed for NVI. On the SVI continental shelf and in both shelf and offshore NVI, annual average anomalies of the subarctic oceanic copepods and northern chaetognaths changed to slightly negative in 2013 but were much weaker than the strong negative anomalies of the warmer years 1995-1998. Subarctic oceanic copepods are typically found along the shelf break in the spring so the expectation is that they would do better in the offshore environment than on the shelf. The warm-water southern origin copepods had weak annual negative anomalies except in the SVI offshore sub-region where the late summer warming led to a positive annual anomaly (Fig. 15.3). However, the shift toward a southern community was also much less pronounced than in 2007-2009.

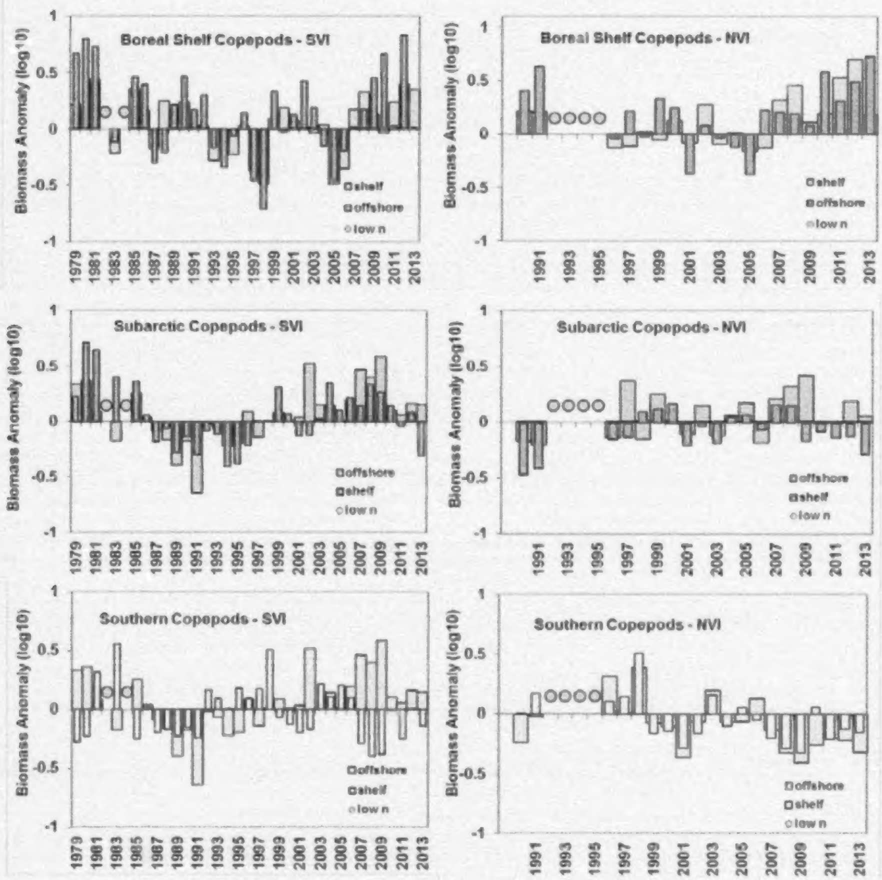

Figure 15.3. Comparison of copepod anomaly time series for shelf and offshore subregions SVI (left panels) and NVI (right panels). Before 2006, anomaly time series from shelf and offshore usually shared the same sign and had similar magnitudes. Since then, the offshore subregion has had positive summer anomalies of southern origin taxa even in cool years. Note: Time series for SVI is 1979 to present, and for NVI from 1990 to present.

After the copepods, euphausiids are the dominant zooplankton taxa in most BC regions. The 2013 euphausiids anomalies were similar to 2010-2012 (Fig. 15.4), except the SVI offshore sub region where *Euphausia pacifica* anomalies became strongly negative. *E. pacifica* is an oceanic species, *Thysanoessa spinifera* is a shelf species so the expectations are that *E. pacifica* would do much better in the offshore regions which is true for NVI but not for SVI.

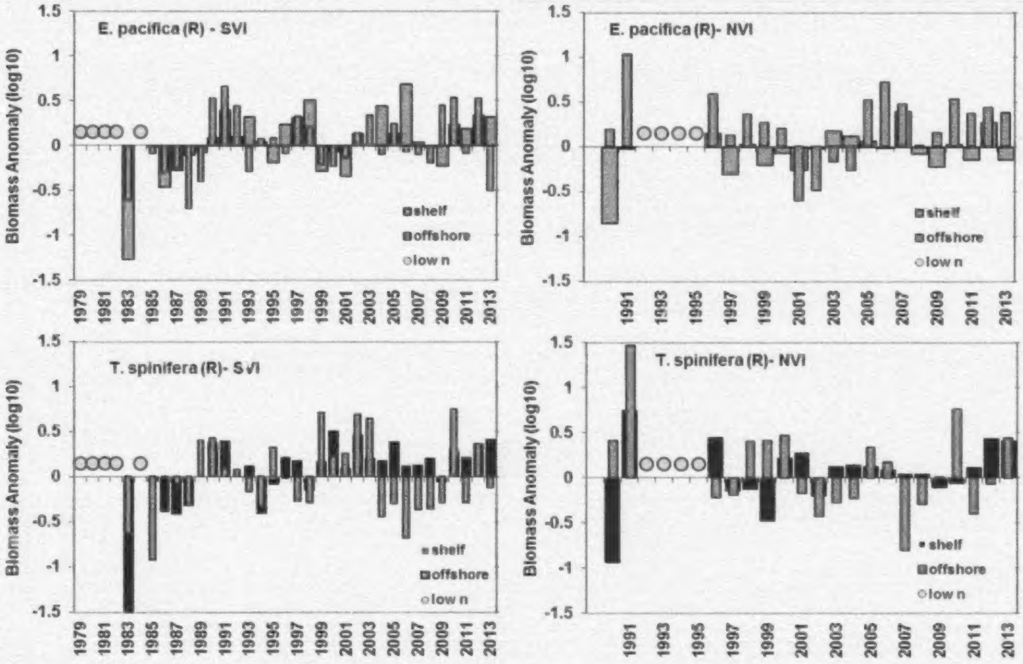

Figure 15.4. Comparison of euphausiid anomaly time series from SVI (left panels) and NVI (right panels) for shelf and offshore subregions. (R refers to corrected for day and night sampling)

Several high-order zooplankton taxa (with widely differing ecological niches) are classified as "gelatinous zooplankton". However, all have high to very high peak reproductive rates compared to the crustaceans and chaetognaths, and all tend to have "boom and bust" population time series. The most important gelatinous zooplankton groups in the SVI and NVI regions are:

- Salps and doliolids. These are planktonic tunicates, and are primarily herbivorous (broad spectrum filter feeders)
- Thecosomatous pteropods (e.g. *Clio pyramidata*). These are planktonic snails. Unlike the previous two groups, their bodies are not gelatinous, but they use a large external gelatinous feeding web to capture their food.
- Hydromedusae and scyphomedusae ("jellyfish") and ctenophores ("comb jellies"). These are predatory on other zooplankton, sometimes on larval fishes but mainly competitors with larval fish.

Doliolids and the pteropod *Clio* were absent or rare in nearly all years before 2002, but since then have been abundant to very abundant in the SVI region in many years (and nearly as abundant in the NVI region). Years with positive salp anomalies have occurred throughout the time series, but both years 2009 and 2010 were well above average; 2013 is a slight positive (Fig. 15.5). A similar pattern is present in the jellyfish with slight decline of hydromedusae in the SVI region. For the past three years ctenophores have seen a positive trend in both NVI and

SVI which has been consistent over the shelf and offshore areas (although not near the historic highs of the early nineties). For 2013, a warm water pteropod, *Corolla spectabilis* was found on the shelf and offshore areas of SVI; last known occurrence was in 2005/6 and 1997/98. As with the long term trend in the copepod species groups, the net effect has been to make the zooplankton community off BC more like the community found in nearshore parts of the California Current System to the south of BC, less like the historical SVI and NVI climatology, and less like the present-day zooplankton community off northern British Columbia and Alaska.

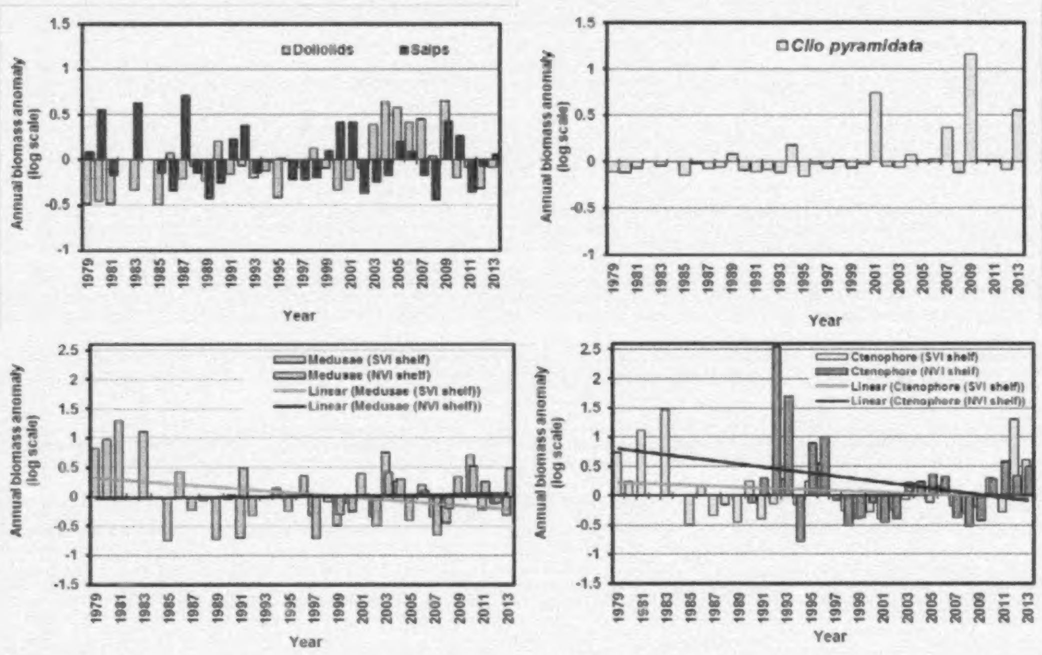

Figure 15.5. Anomaly time series for important gelatinous zooplankton off southern Vancouver Island. Top left panel shows doliolids (genus Dolioletta*) and salps (genus* Salpa*) in the SVI region. Top right panel shows the warm water thecosomatous pteropod* Clio pyramidata*. Their frequency and intensity of occurrence has increased dramatically since about 2000. Bottom left shows hydromedusae in the SVI and NVI regions. The large positive anomaly in 2010 consisted of* Mitrocoma*. Bottom right panel shows ctenophores, mainly* Pleurobrachia bachei*, in the SVI and NVI regions.*

With the interest in ocean acidification we have included anomaly trends for *Limacina helicina*, a pelagic thecosomate (shelled) pteropod with a calcareous shell susceptible to dissolution damage if water in the top 100m is under saturated for aragonite. The overall trend for *L. helicina* is negative; the large positive anomaly in 2013 in NVI was a result of sampling in cool spring conditions along the shelf and shelf break (Fig. 15.6), described earlier in text. The anomaly would have been higher without the moderating effect of low numbers encountered in the September samples. *L. helicina* is the prey item for *Clione limacina*, a gymnosomate (no shell) pteropod. *Clione* numbers have been increasing off the WCVI for some time, suggesting that *Clione* must have an alternate food source. We speculate that they are feeding on *Clio* but this remains to be confirmed.

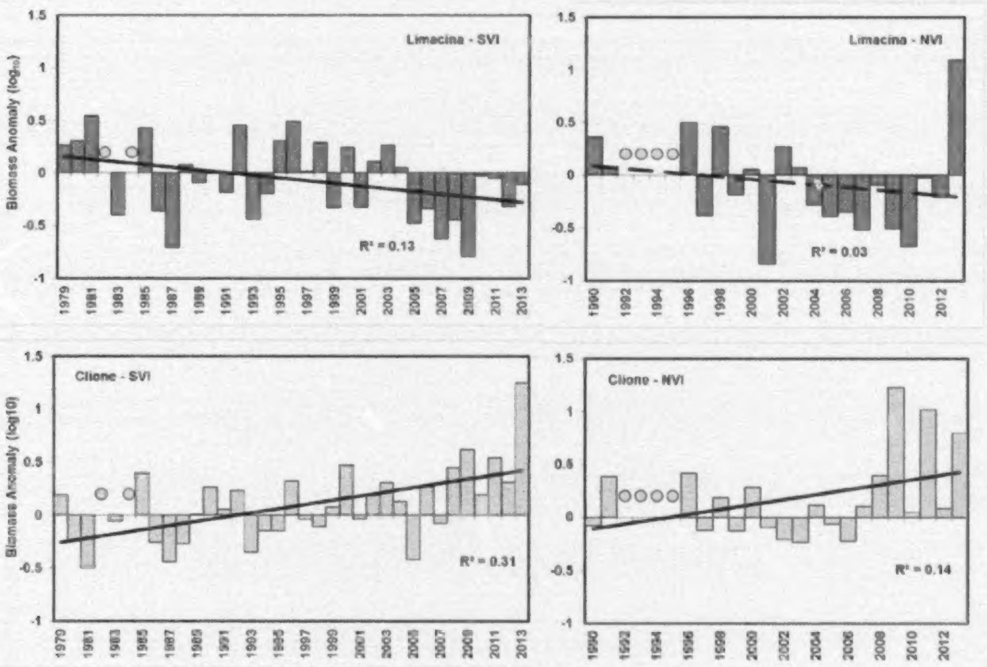

Figure 15.6. Anomaly time series for Limacina helicina *(top panels) and* Clione limacina *(bottom panels) with linear trend showing an interesting predator/prey relationship.*

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16. Small-mesh bottom-trawl surveys west of Vancouver Island: update for 2013

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Bottom trawl surveys using a small-mesh net (targeting the Smooth Pink Shrimp *Pandalus jordani*) have been conducted during May since 1973 in two regions, and since 1996 in three regions, off the west coast of Vancouver Island (Fig. 16.1). The survey masks for these regions, over which the total biomass of each species has been estimated, are generally bounded between the 100m and 200m depth contour lines for Areas 124 and 125.

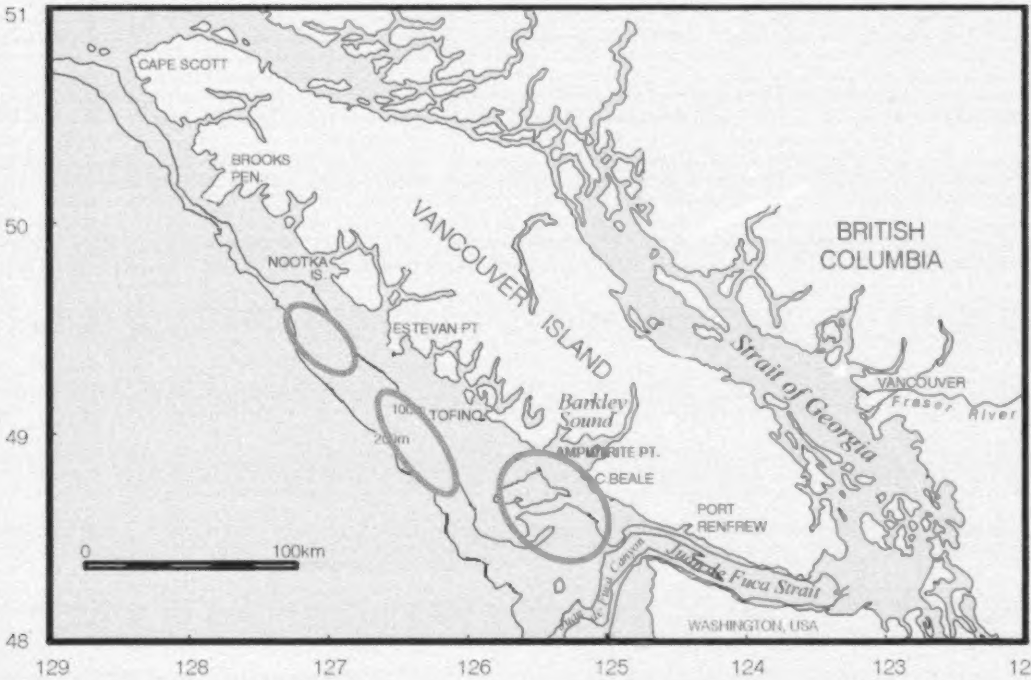

*Figure 16.1. Map showing the three main shrimp (*Pandalus jordani*) fishing grounds off Vancouver Island (red ovals) considered in this report. The Nootka (Area 125) and Tofino (Area 124) Grounds are the northern and middle ovals, respectively, and have been surveyed since 1973. The southern oval represents the shrimp fishing grounds off Barkley Sound, surveyed since 1996.*

This small-mesh bottom trawl survey was designed to target Smooth Pink Shrimp on the shrimp fishing grounds in a relatively small area off the west coast of Vancouver Island. Biomass estimates of other taxa caught along with Smooth Pink Shrimp may, or may not, be reliable depending on whether these other taxa are highly mobile in and out of the survey area or are highly patchy in their distribution. An autocorrelation analysis indicates that of the 36 taxa regularly sampled by this survey, 16 of them appear to be well-sampled (i.e. have positive autocorrelations of at least lag 1 year; Table 16.1). Of those species shown in Fig. 16.2, all are well-sampled by this survey gear except for spiny dogfish and Pacific hake (English sole is marginally sampled by this survey).

Pelagics	Demersals		Benthics
Pacific hake	Silvergrey rockfish	Pacific cod	Sea mouse
American shad	Darkblotch rockfish	Sablefish	Heart urchin
Pacific herring	Green rockfish	Lingcod	Sea urchins
Eulachon	Yellowtail rockfish	Ratfish	Sea cucumber
Dogfish	Boccacio	Smooth pink shrimp	
Walleye pollock	Canary rockfish	Dover sole	
	Redstripe rockfish	Pacific sanddab	
	Pacific Ocean perch	Petrale sole	
	Arrowtooth flounder	Rex sole	
	English sole	Flathead sole	
	Pacific halibut	Slender sole	
	Yelloweye rockfish	Spot Prawn	

Blue taxa names represent no significant autocorrelations

Table 16.1. List of 'core' taxa which have been sampled routinely during these small mesh surveys since 1973 and for which annual biomass estimates are calculated. Taxa in black are those with significant ($p<0.05$) autocorrelations and which are therefore considered to be well-sampled by this survey.

Surveys in May 2013 found the biomass of *Pandalus jordani* shrimp off central Vancouver Island continued to increase from the recent low value in 2011 (Fig. 16.2). The biomass of Pacific Halibut and English Sole remained lower in 2013 compared with the early 2000's, but higher than during the 1970's and 1980's. The biomass of Arrowtooth Flounder in 2013 was among the higher values in the survey time series. The biomass of Walleye Pollock (*Theragra chalcogramma*, a cold water species) dropped to near normal levels in 2013 compared with 2012.

Smooth Pink Shrimp biomass in a given year is weakly related to the mean spring (April, May, June) sea surface temperature at Amphitrite Point on the west coast of Vancouver Island two years previously [regression of shrimp biomass (yr = i) versus SST (AMJ yr = i-2): $R^2 = 0.24$, $P<<0.01$]. The regression is improved considerably when Pacific Hake biomass measured during these surveys in April in the current year (yr = i) are included. Using Amphitrite SST data from spring 2012 and 2013 and the relationship between SST and Smooth Pink Shrimp biomass provides estimates of potential trends in shrimp biomass for 2014 and 2015, projecting a continued increase in shrimp biomass in 2014 and a decline in 2015 (Fig. 16.3).

Based on these well-sampled taxa, survey years from 1973 to 2013 were clustered to identify years with similar taxonomic compositions, using a chronological clustering method. Results indicate seven clusters, with one outlier year (2002). The largest composition change separated 1996 and prior years from 1997 and subsequent years (Fig. 16.4).

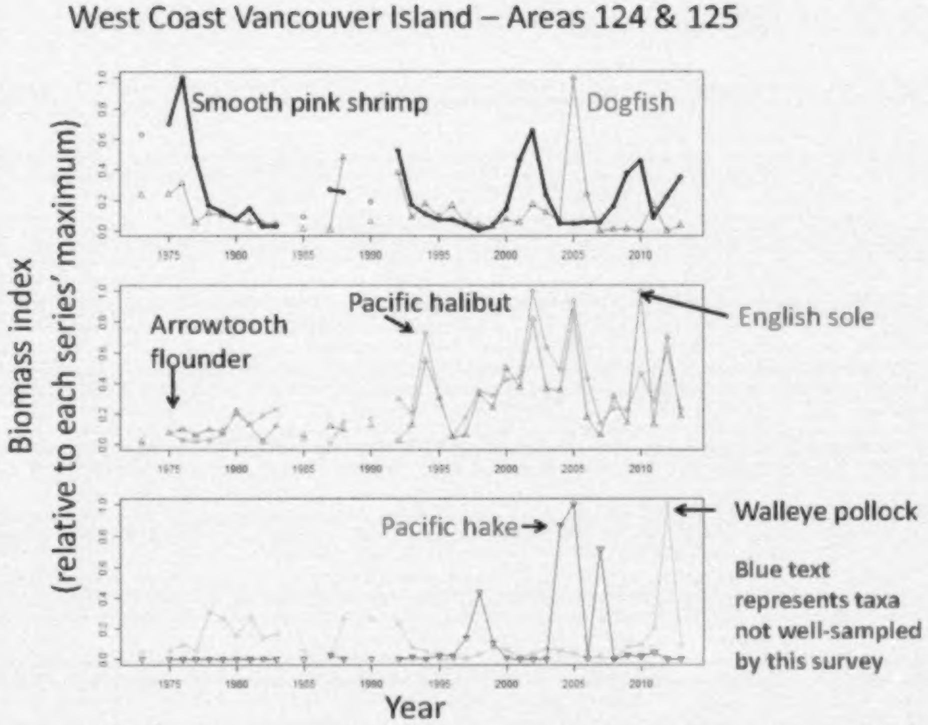

Figure 16.2. Time series of normalised (to maximum biomass) survey catches in Areas 124 and 125 of Smooth Pink Shrimp, Dogfish, Pacific Halibut, Arrowtooth Flounder, English Sole, Pacific Hake and Walleye Pollock. Sampling was conducted in May of each year. Blue text identifies those taxa believed to be not well-sampled by the survey, based on an autocorrelation analysis.

Conclusions from this analysis are the following:

- pink shrimp biomass in Areas 124-125 in 2013 continued to increase from its low value in 2011. This is likely as a result of cooler waters since 2011 and 2012 (pink shrimp have a 2-yr lag from hatch to recruitment at age-2);
- based on relationships with April-May-June sea surface temperature measured along the west coast of Vancouver Island two years previously, pink shrimp biomass in Areas 124-125 is projected to continue to increase slightly in 2014 but decline slightly in 2015;
- the composition of the "well-sampled" taxa show changes which correspond to the 'canonical' regime shifts described for the NE Pacific from 1970 to 1990;
- the composition of the "well-sampled" taxa show further changes in the 2000's, most recently between 2006-2009 and 2010-2013 (i.e. on a multiple species basis, 2013 was similar to 2010-2012);
- the largest composition change occurred between 1996 and 1997.

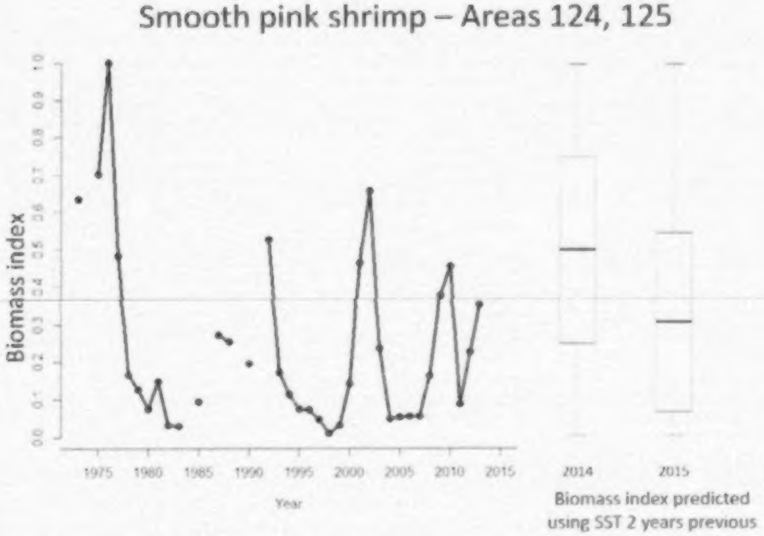

Figure 16.3. Time series of normalised (to maximum biomass) survey catches in Areas 124 and 125 of Smooth Pink Shrimp (left graph). Shown on the right are projections (as boxplots; horizontal bar represents the median estimate) of the biomass of Smooth Pink Shrimp based on a regression with mean sea surface temperature at Amphitrite Point (west coast Vancouver Island) in April, May and June two years previously (2014 projections based on SST from 2012; 2015 projections based on SST from 2013).

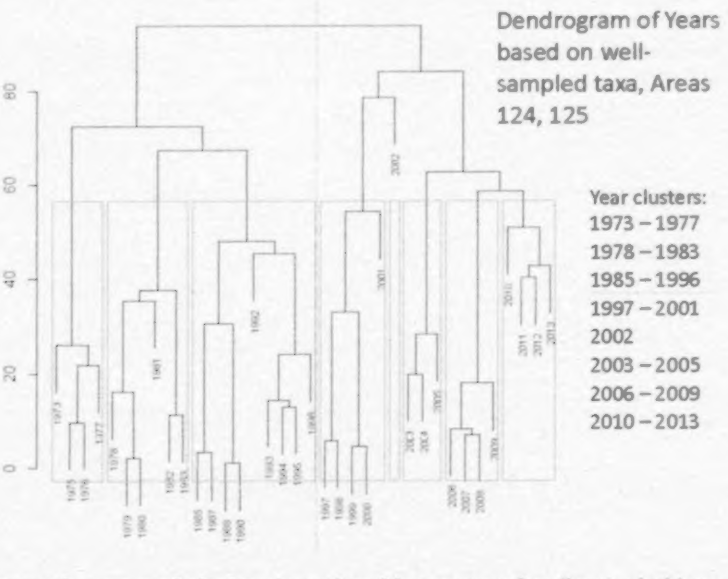

Figure 16.4. Dendrogram of years and clusters based on biomasses of well-sampled taxa (black font taxa in Table 1) using a chronological clustering method. The largest break separated clusters in 1996 and prior years from 1997 and subsequent years. Sampling was conducted in May of each year.

17. Pacific Herring in British Columbia, 2013

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Description of index

Model estimates of Pacific Herring biomass, based on commercial and test fishery biological samples (age, length, weight, sex, etc.), herring spawn dive survey data (spawn index), and commercial harvest data, provide an index of herring population trends for five major fishing stocks: Strait of Georgia (SOG), west coast of Vancouver Island (WCVI), Prince Rupert District (PRD), Haida Gwaii (HG; previously referred to as the Queen Charlotte Islands stock), and the central coast (CC), and two minor stocks (Area 2W and Area 27) (DFO 2014; Fig. 17.1). In 2013, an integrated statistical catch-age model was used to provide (in part) estimates of Pacific Herring spawning biomass and age-2 recruit abundances (DFO 2014).

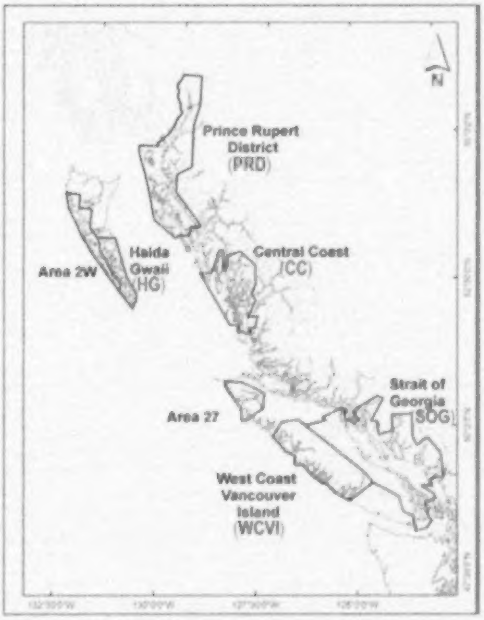

Figure 17.1. Location of the five major (Strait of Georgia, west coast of Vancouver Island, Prince Rupert, Haida Gwaii, and the Central Coast) and two minor (Area 2W and Area 27) Pacific herring fishing stocks in British Columbia.

Status and trends

West Coast Vancouver Island (WCVI): The median spawning biomass has increased since 2008 (Fig. 17.2) from historically low levels due in part to above average recruitment in 2010 (Fig. 17.3) and apparent decreases in model estimates of natural mortality. The WCVI stock was closed to commercial fisheries from 2006 to 2011 and in 2013. A commercial harvest option was available in 2012 but was not pursued. WCVI herring weight-at-age has declined since the mid-1970s or mid-1980s (Fig. 17.4).

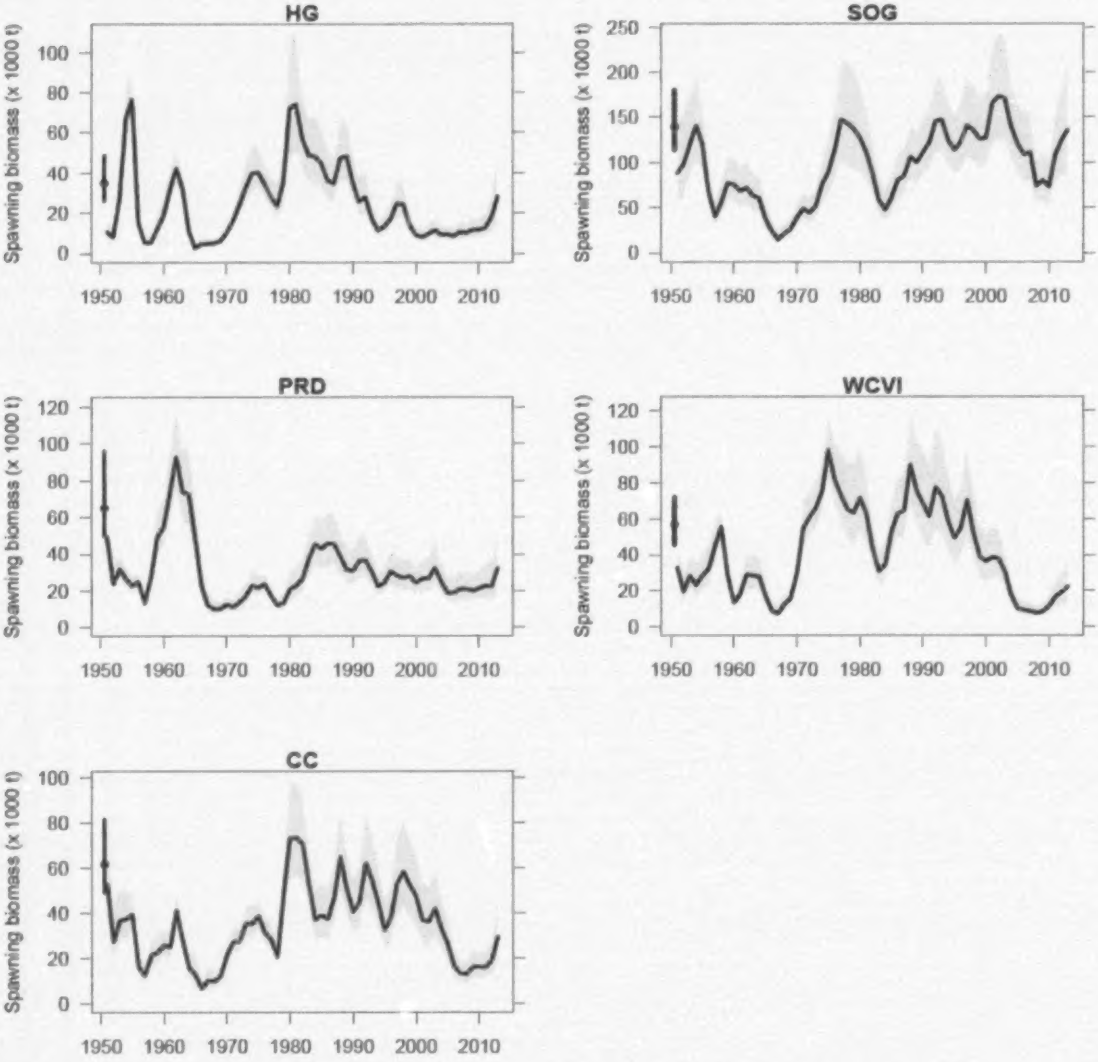

Figure 17.2. Median of the posterior distribution for spawning biomass (solid line) with 90% posterior credibility intervals (shaded area) for the five major stock areas, 1950-2013. Biomass is in thousands of metric tonnes and scales differ between panels. Solid circle represents the estimated unfished equilibrium spawning biomass with 90% posterior credibility intervals (vertical lines).

Strait of Georgia (SOG): The median spawning biomass has increased since 2010 (Fig. 17.2) due in part to above average recruitment in 2010 and 2011 (Fig. 17.3) and apparent decreases in model estimates of natural mortality. The 2013 catch in the winter seine fishery (food and bait, special use) was 4,530 t, in the seine roe fishery was 6,099 t, and in the gillnet roe fishery was 5,937 t. SOG herring weight-at-age has declined since the mid-1970s (Fig. 17.4).

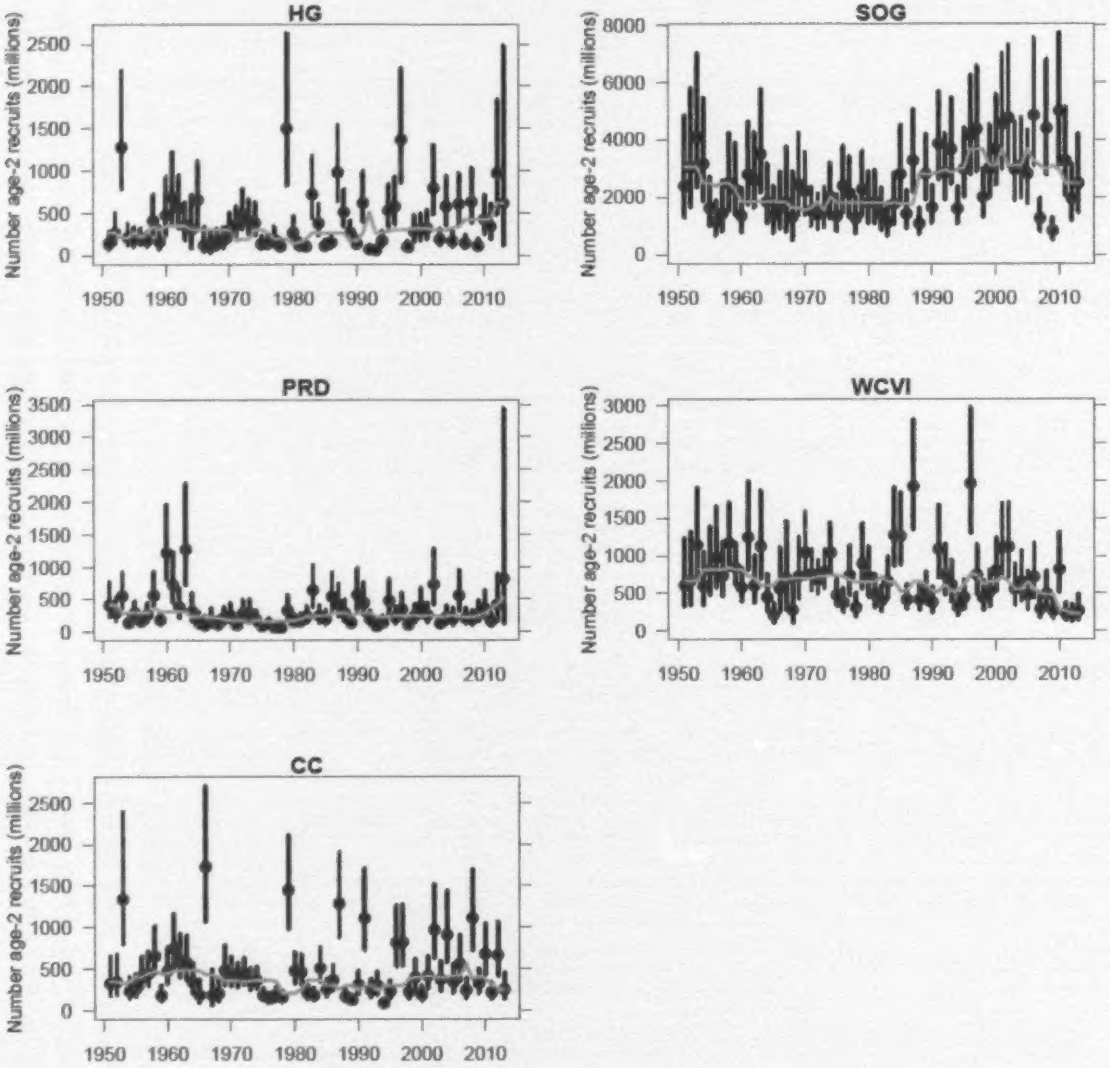

Figure 17.3. Median posterior estimates (solid circles) of recruitment (millions of age-2 fish) with 90% posterior credibility intervals (vertical lines). Red trend line denotes 5-year running average.

Prince Rupert (PRD), Haida Gwaii (HG), and Central Coast (CC): Exploitable herring biomass in the Pacific North Coast Integrated Management Area (PNCIMA) region represents a combination of migratory stocks from the HG, PRD and CC areas (DFO 2012). In HG, median spawning biomass increased after 2008 (Fig. 17.2), in part due to increases in the spawn index from 2011 to 2013, above average recruitment in 2010 to 2013 (Fig. 17.3), and possibly decreases in model estimates of natural mortality. No commercial herring fishery occurred in this area from 2005 through 2013. In CC, median spawning biomass increased from 2011 through 2013 (Fig. 17.2) in part due to above average recruitment in 2008, 2010, and 2012 (Fig. 17.3), a high spawn index in 2013 (although this was preceded by seven years with low index values), and apparent decreases in model estimates of natural mortality. No commercial herring fishery occurred in this area from 2008 through 2013. In PRD, median spawning biomass has increased since 2012 (Fig. 17.2) as a result of increases in the spawning index (since 2010), above average recruitment in 2013 (Fig. 17.3) and possibly decreases in model estimates of natural mortality. Commercial seine roe and gillnet roe fisheries caught 743 t and 1,284 t, respectively, in 2013. Commercial spawn on kelp operations also occurred (five licenses). PRD, HG, and CC herring weight-at-age has declined since the mid-1970s (Fig. 17.4).

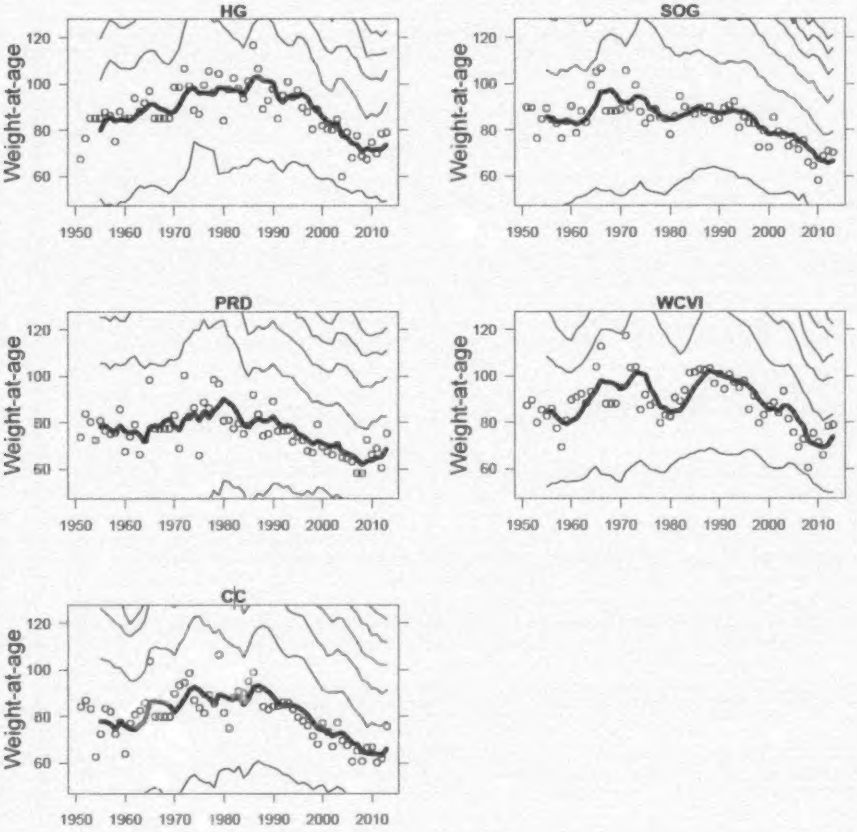

Figure 17.4. Time series of observed weight-at-age 3 (circles) and five-year running mean weight-at-age 3 (thick black line) for major herring stocks. Thinner black lines represent five-year running mean weight-at-age 2 (lowest) and ages 4-7 (incrementing higher from age 3).

Factors causing those trends

The biomass of Pacific Herring in three major fishing stocks (HG, CC, WCVI) have been low in recent years (DFO 2014) despite being closed to fishing; whereas, two areas that are open to fishing have stable or high biomass estimates (PRD, SOG). Consideration of these biomass trends in combination with the declining trend in herring weight-at-age observed for all fish fishing stock areas, suggests that factors other than fishing may be influencing herring population trends. Changes in food supply and quality, predator abundance, and competition are factors that could affect trends in herring biomass and weight-at-age (Schweigert et al. 2010; Hay et al. 2012).

Pacific Herring are zooplanktivorous, consuming primarily euphausiids (krill) and some copepods (Wailes 1936). Changes in ocean conditions, such as temperature or currents, could affect the amount and types of prey available. For example, a northerly current direction could result in the presence of California current waters off the WCVI, bringing California Current zooplankton species that have a lower energetic value, creating poorer feeding conditions for herring (Schweigert et al. 2010, Mackas et al. 2004). In addition, Tanasichuk (2012) related WCVI herring recruitment to the biomass of euphausiids.

There are a wide variety of herring predators, including Pacific Hake, lingcod, Spiny Dogfish, Pacific Cod, sablefish, Arrowtooth Flounder, Pacific Halibut, Steller Sea Lions, Northern Fur Seals, Harbour Seals, California Sea Lions, and Humpback Whales (Schweigert et al. 2010). Off the WCVI, fish predator abundance has decreased in recent years, while the abundance of most marine mammal predators has increased (Olesiuk 2008, Olesiuk et al. 1990). This has resulted in a relatively stable or slightly decreasing trend in the amount of WCVI herring consumed by predators since 1973 (Schweigert et al. 2010). Although a significant proportion of the herring population could be cropped annually by predation, trends in model estimates of natural mortality of WCVI herring were not found to be directly attributable to trends in estimates of predation (Schweigert et al. 2010). Herring recruitment, however, has been correlated with piscivorous hake biomass (piscivorous hake are those hake that are large enough to consume herring), suggesting predation may be an important factor influencing WCVI herring recruitment (Tanasichuk 2012).

Competition may also be a factor affecting herring population trends. Since the late 1990s, a substantial component of the Pacific Sardine population off the west coast of North America has migrated into Canadian waters annually until 2013 (see Flostrand et al. this volume). The large increases in Pacific Sardine in the early 1990s to 2000s in Canadian waters may have increased competition for food with herring, and/or attracted predators (Schweigert et al. 2010). A Strategic Program for Ecosystem-Based Research and Advice (SPERA) project was funded (2012/13) to assess the potential for competitive interactions between sardine and herring.

Implications of those trends

Trends in herring biomass have implications for both fisheries and predators. Pacific Herring comprise an important component of commercial fisheries in British Columbia. Fisheries Management uses forecasts of herring biomass, in conjunction with decision tables, performance metrics, and harvest rates to set total allowable catches (TAC).

Trends in herring biomass have implications for herring predators, such as fish, marine mammals and seabirds. The relative importance of herring in each predator's diet varies; however, herring may represent up to 88% of lingcod diet (Pearsall and Fargo 2007), 40% of Pacific Cod and Pacific Halibut diets (Ware and McFarlane 1986), and 35% - 45% of pinniped diets (Olesiuk et al. 1990, Womble and Sigler 2006, Trites et al. 2007, Olesiuk 2008). Depending on the level of diet specialization and ability to switch to alternate prey, herring abundance and condition may affect predators' growth and abundance. Time series of diets of animals in this ecosystem would improve our ability to examine temporal trends in predator-prey interactions and implications of those trends.

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18. Sardine and other pelagic species sampled in the pelagic ecosystem night time survey

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Description of indices

Indices of Pacific Sardine (*Sardinops sajax*) population trends are based on a summer surface trawl survey by DFO off the west coast of Vancouver Island (WCVI), commercial sardine landings from British Columbia (BC), and a population stock assessment led by scientists in the United States (US). The WCVI survey began in 1997, and switched to night-time sampling in 2006, after a 2005 survey found the mean results of day and night sampling to be comparable but day sampling had greater variance. Sample stations are chosen randomly within a core survey area. Annual WCVI catch per unit effort (CPUE) data are applied to estimate the regional biomass for the WCVI region. In addition to sardine, other pelagic fish species (such as Pacific Herring) are sampled. Average CPUE of other species are examined qualitatively for changes in species composition The population stock assessment applies a Stock Synthesis model to estimate population biomass; the model integrates data from several research surveys (acoustic-trawl, ichthyoplankton and aerial) and from commercial catches in the US, Canada and near Ensenada Mexico (Hill et al. 2012, Hill 2013)

Status and trends

Large aggregations of Pacific sardine from the California Current population seasonally migrate between southern California, where they spawn during winter and spring months, and the Pacific Northwest (Oregon, Washington and BC) where they forage in nutrient rich waters mainly during summer and fall months. The older and larger fish tend to move the furthest north (Clark and Janssen 1945, Flostrand et al. 2011). Historically, the BC sardine fishery collapsed in 1947 and the California fishery collapsed by the early 1950s. Sardine returned to southern Vancouver Island waters in 1992 after a 45-year absence, and expanded their seasonal distribution northward throughout the WCVI, Hecate Strait and Dixon Entrance by 1998 (McFarlane et al. 2001).

In 2013, a pelagic ecosystem night time trawl survey was conducted by DFO off the WCVI from August 6 to 16 and no Pacific Sardine were observed in any of the 60 tows. Estimates of mean Pacific Sardine trawl catch densities (tonnes/km^3) from this survey showed a decreasing trend during 2006 and 2008-2012 (Figs. 18.1 and 18.2, DFO 2013).

In 2013, no landings were made by the BC sardine fishery due to an apparent absence of sardine in BC waters. Prior to 2013, commercial purse seine fishing for sardine in BC has been conducted in sheltered waters (especially inlets) off the WCVI and in waters of the Pacific North Coast Integrated Management Area (PNCIMA) such as off the southern Central Coast, in the Queen Charlotte Strait and Queen Charlotte Sound. From 2002-2012, both the annual total allowable catch (TAC) and landings generally increased as a result of management decisions (DFO 2012). Landings were relatively low prior to 2008 (less than 5,000 tonnes), then following management and policy changes increased over 2009-2012 (10,435 - 22,223 tonnes, Table 18.1).

Spawning stock biomass estimates from the US Stock Synthesis population model show a decreasing trend from over 1 million tonnes in 2007 to between 300,000 and 400,000 tonnes in

2013 (Fig. 18.3). Recent assessments also show no indication of a greater than average year class since 2009 (Fig. 18.4, Hill et al. 2012; Hill 2013). Trends in recruitment year class strength are correlated with decreases in population biomass and WCVI summer survey biomass.

The composition of other species sampled in the pelagic ecosystem nighttime survey varies annually, but is composed mainly of (in addition to Pacific Sardine) Pacific Herring, Pink Salmon, Sockeye Salmon, Coho Salmon, Chinook Salmon, and Spiny Dogfish. In 2013, the primary species caught were Pink Salmon and Pacific Herring. Species that were prevalent in a high proportion of tows and/or had high catches included Pink Salmon (54 tows), Pacific Herring (32 tows), Coho Salmon (45 tows), Chinook Salmon (31 tows) and Spiny Dogfish (4 tows).

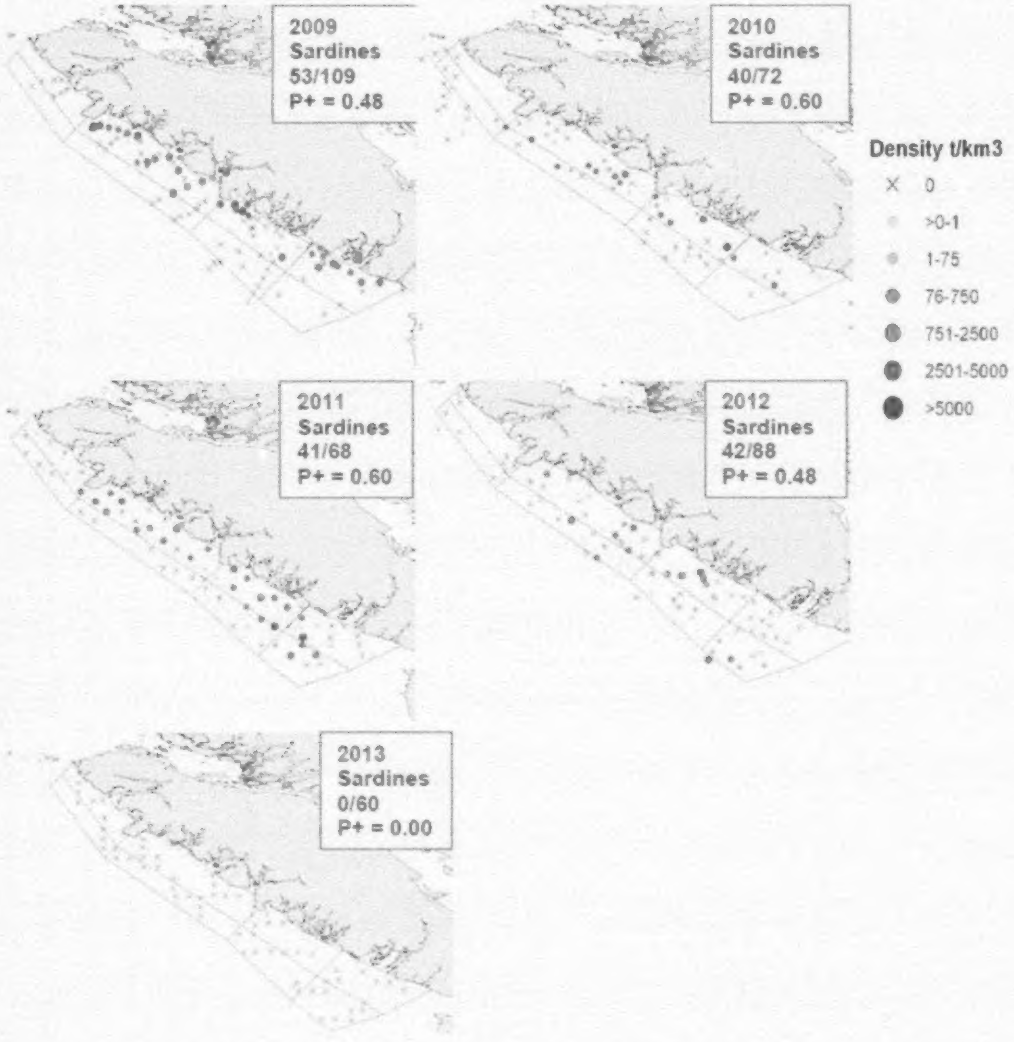

Figure 18.1. West coast of Vancouver Island summer trawl survey sampling locations and relative sardine catch densities for 2009-2013 (tonnes per km^3 trawled). Lines delineate zones for possible regional stratification. P+ = the fraction of tows where sardine were caught.

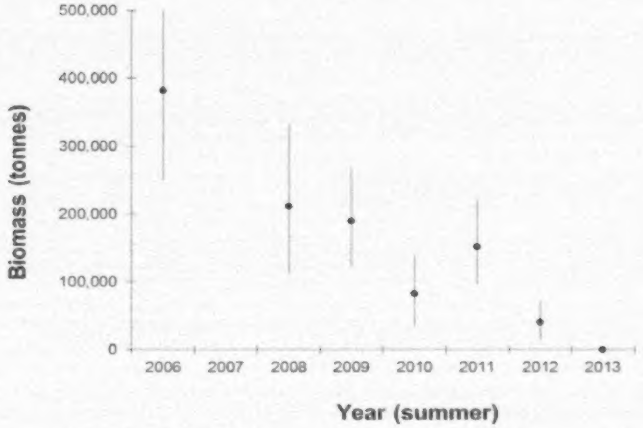

Figure 18.2. West coast of Vancouver Island (WCVI) summer trawl survey 2006, 2008-2013 biomass estimates and 90% confidence intervals. Survey conducted mid-summer (end of July/early August).

Table 18.1. Annual sardine total allowable catch (TAC) and purse seine landings for British Columbia (BC), from the west coast of Vancouver Island (WCVI) and the Pacific North Coast Integrated Management Area (PNCIMA), in tonnes.

Year	BC TAC	BC Landings	WCVI Landings	PNCIMA Landings
2002	5,040	822	482	340
2003	9,000	1,006	1,006	0
2004	15,000	4,259	4,179	80
2005	15,200	3,266	595	2670
2006	13,500	1,558	0	1,558
2007	19,800	1,507	275	1,232
2008	12,491	10,435	5,670	4,765
2009	18,196	15,334	8,073	7,262
2010	23,166	22,223	18,911	3,312
2011	21,917	20,719	20,718	0
2012	27,279	19,129	19,129	0
2013	25,477	0	0	0

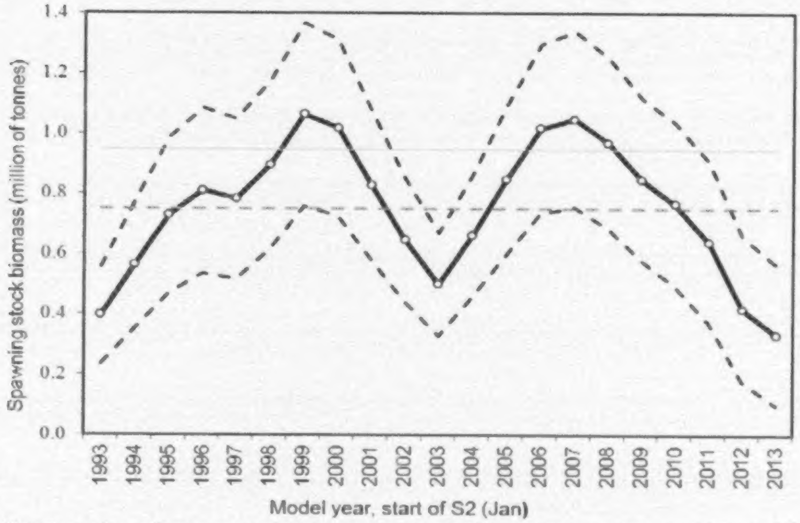

Figure 18.3. Estimates of sardine spawner biomass with 95% confidence interval from Stock Synthesis population model (Hill, 2013). Average estimate =751,437 tonnes (dashed red line), virgin biomass estimate = 946,472 tonnes (solid green line).

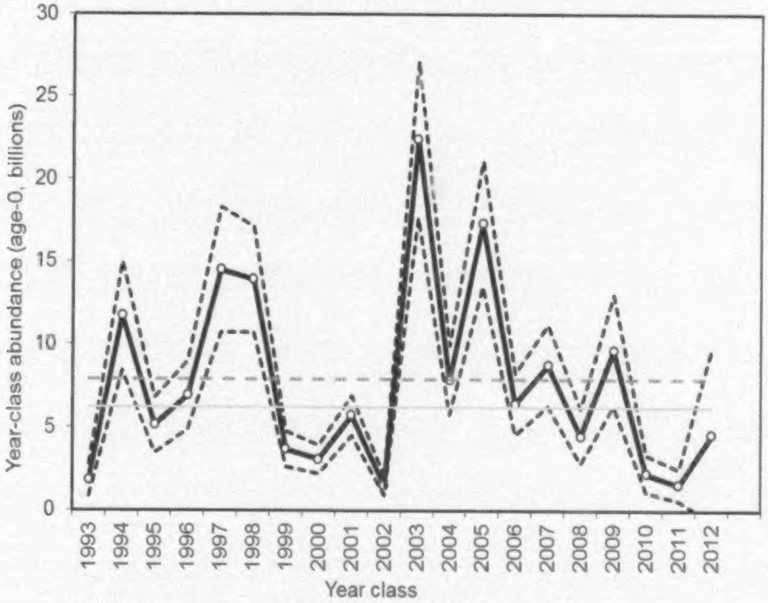

Figure 18.4. Estimates of recruiting juveniles (billions of age-0 fish) and 95% confidence interval. Information from Hill 2013. Average estimate =7.92 billion (dashed red line), virgin recruitment estimate = 6.22 billion (solid green line).

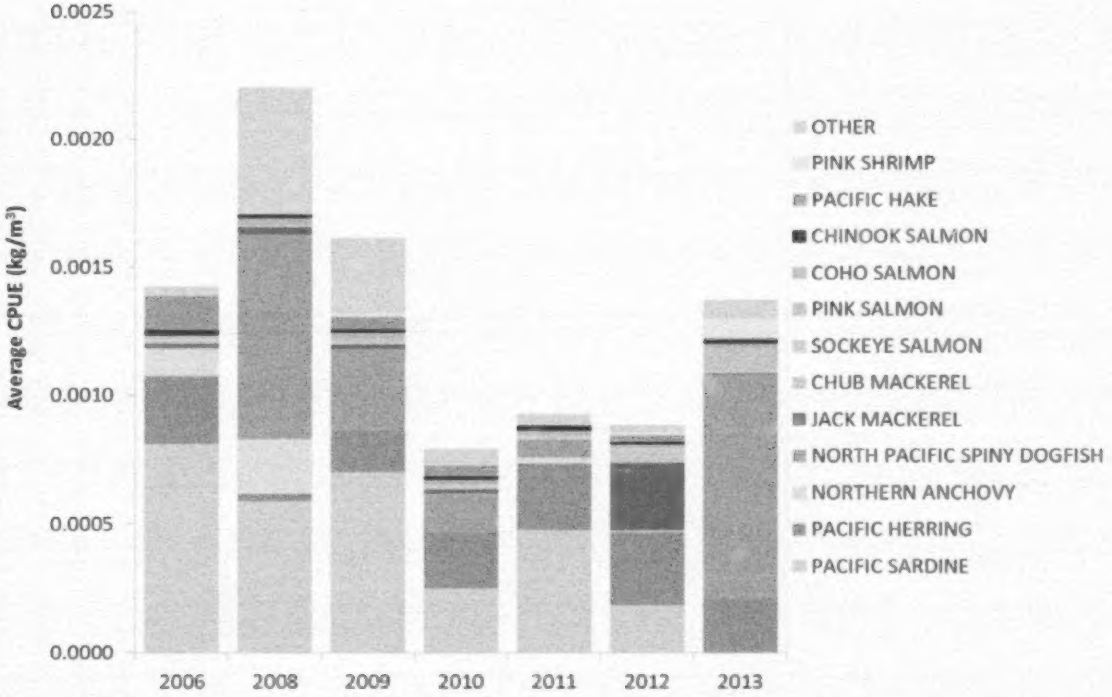

Figure 18.5. Average CPUE (kg/m3) of pelagic species sampled in the pelagic ecosystem night time trawl survey. Large average CPUE values in any one year can be the result of one or two large catches (e.g., dogfish in 2013).

Factors causing trends in abundance and distribution

The absence of a recent strong year class of Pacific sardine appears to be a main cause for estimated decreases in the biomass for the population and for the WCVI summer survey. Historical sardine abundance has been extremely variable along the US and Canadian west coast, cycling over approximately 60-year periods (Cushing 1971, Hill et al. 2011). The abundance of sardines and the timing of their annual northward migration are influenced, in part, by environmental factors and stock size, age and size composition and recruitment relationships that are not well understood (Lo et al. 2010, Hill et al. 2012). The decline in sardine biomass in the late 1940s was attributed to environmental conditions and overfishing (Clark and Marr 1955, Jacobson and MacCall 1995). During cold years, such as in the 1950s to 1970s, sardine productivity appears generally low and the population's distribution can contract to the southern part of the range (Hill et al. 2011, Jacobson and MacCall 1995). During warm years, such as in the 1990s and in 2003-2007, increases in sardine productivity are apparent (Jacobson and MacCall 1995) and larger stock size has resulted in a more northerly seasonal distribution of the stock (McFarlane et al. 2001, Hill et al. 2011, Zwolinski et al. 2011, Zwolinski et al. 2012). In 2012 and 2013, mid-summer migration to BC waters appears to have been relatively low due to a combination of cooler summer ocean conditions, contracted northward migration and reductions in overall population size.

Changes in species composition in the pelagic ecosystem nighttime survey are likely due to a variety of environmental and biological factors. In addition, CPUE estimates (Figure 5) can be influenced by one or two trawl hauls (e.g., 2013 average Spiny Dogfish CPUE was influenced by one large catch). Further quantitative analysis of these data is in progress to improve the understanding of factors affecting the relative abundance and distribution of pelagic fish species.

Implications of those trends

The resurgence of a commercial BC sardine fishery in 2002 followed the recovery of the coastwide population and the return of sardine to BC waters in the 1990s. The general absence of sardine in BC waters in 2013 was unexpected and relates to a high degree of uncertainty associated with the population's productivity, distribution and general ecology. If sardine migration to BC waters and population biomass continue to be low, the BC sardine fishery is at risk.

In BC waters, Pacific sardine are consumed by a variety of fish, such as Coho and Chinook Salmon (Chapman 1936), Spiny Dogfish and other sharks, Albacore Tuna and other tuna, Pacific Hake, Jack Mackerel as well as by marine mammals, such as Humpback Whales, California Sea Lions and other pinnipeds. Historically, sardine populations have undergone extreme variations in abundance and it is likely that many predators utilize this resource when it is abundant. However, changes in sardine abundance and distribution would also likely influence the distribution of some of their migratory predators. A time series of diet data from sardine predators would improve our ability to examine temporal trends in predator-prey interactions and the implications of those trends.

Changes in species composition, relative abundance, and distribution can be indicative of ecosystem-wide changes and can have implications for other trophic levels (both prey and predators). A clearer understanding of the environmental and biological factors affecting pelagic species and their interactions and trophodynamics is needed.

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19. Eulachon

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Description of indices

Three indices of Pacific Eulachon (*Thaleichthys pacificus)* population trends are: 1) eulachon catches occurring in annual offshore shrimp trawl surveys off the West Coast of Vancouver Island (WCVI, 1973-2012) and in Queen Charlotte Sound (QCS, 1998-2012), 2) commercial eulachon catches in the Fraser (1900-2004) and Columbia (1888-2010) River systems, and 3) a spawning stock biomass estimate based on annual Fraser River eulachon egg and larval surveys, 1995 to 2013. In the past, information from these indices was used to assess population trends and provide science advice regarding Eulachon catch recommendations. Offshore indices of juvenile eulachon abundance, however, do not reflect the abundance of adult eulachon that return to rivers (Schweigert et al. 2012) and Fraser River and Columbia River commercial fisheries have been closed in recent years; therefore, the only updated index presented here is the spawning stock biomass estimate based on annual Fraser River eulachon egg and larval surveys.

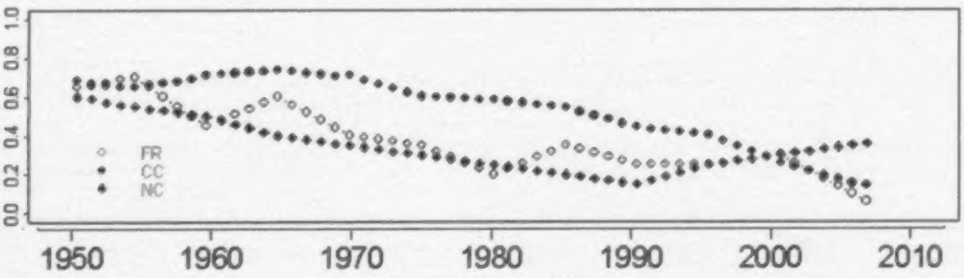
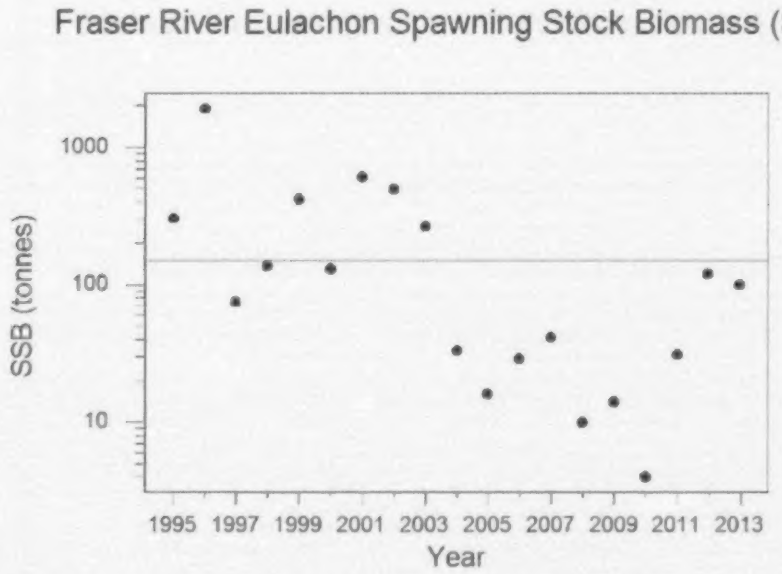


Figure 19.1. Estimated relative abundance trends for the three BC eulachon designated units (DU); adapted from Schweigert et al. (2012). FR = Fraser DU, CC = central coast DU, NC = Nass/Skeena DU (symbols with post-1990 increasing trend). Y-axis is expressed in unit-less, relative values.

Status and trends

Eulachon have experienced long-term declines in many rivers throughout their distribution from California to Alaska. Indices of eulachon abundance in central and southern British Columbia rivers remain at low levels (Fig. 19.1). The estimated eulachon spawning stock biomass in the Fraser River decreased during 1994-2010 with slight increases in 2011 and 2012; the 2013 biomass estimate was slightly lower than the 2012 estimate (Fig. 19.2). The spawning stock biomass has been below the action level (150 tonnes; Hay et al. 2003) since 2004. The biomass in the Fraser River will be estimated by an egg and larval survey in April-May, 2014. Catches in the Columbia

River system decreased dramatically in the early-1990s. Columbia River eulachon were federally-listed in the U.S.A. as threatened under the Endangered Species Act (ESA) effective May 17, 2010 and all eulachon-directed fisheries were closed in 2011 (NOAA). COSEWIC assessed eulachon in BC as three populations (or designated units): the Central Pacific coast population and Fraser River populations were assessed as endangered, and the Nass/Skeena Rivers population was assessed as Special Concern (COSEWIC 2011). Information in support of a recovery potential assessment (Levesque and Therriault 2011) and a recovery potential assessment are available online (Schweigert et al. 2012).



Note: Log SSB scale. Violet=150t action level.

Figure 19.2. Estimated spawning stock biomass (SSB in tonnes) of eulachon in the Fraser River, 1995-2013. Y-axis is on a log-scale. Horizontal violet line shows 150 tonne action level.

Factors causing those trends

It is unknown what caused declining trends in eulachon abundance. Schweigert et al. (2012) state that "No single threat could be identified as most probable for the observed decline in abundances among DUs or in limiting recovery. However, mortality associated with coastwide changes in climate, fishing (direct and bycatch) and marine predation were considered to be greater threats at the DU level, than changes in habitat or predation within spawning rivers."

Implications of those trends

Reduced biomass of eulachon has negative implications for First Nations and commercial fishers. Eulachon are socially and culturally significant to local First Nations and are fished by First Nations, recreational and commercial fishers.

Reduced eulachon abundance also likely has negative impacts on their predators. Important predators of eulachon include: marine mammals particularly sea lions in the estuaries, and porpoises, Chinook and coho salmon, spiny dogfish, Pacific hake, sturgeon, Pacific halibut, walleye pollock, sablefish, rockfish, arrowtooth flounder, and others (Levesque and Therriault 2011). Diet data time series of all animals in the ecosystem would improve our ability to examine temporal trends in predator-prey interactions and the implications of those trends.

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20. Reduced Catches and Growth of Juvenile Salmon off WCVI in 2013 relative to 2012

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Ocean surveys for juvenile salmon have been used to assess the distribution, growth, condition, and survival of Pacific salmon in different parts of the British Columbia coastal ecosystem since 1998. These surveys are usually conducted in late spring-early summer (June-July) and in the fall (October-November). In addition, juvenile salmon have been collected during winter (February-March) since 2001. This work assumes that marine survival will be higher in years when salmon are rapidly growing and are in good condition than in years of poor growth and condition. Hence, marine survival is expected to be positively correlated to indicators of juvenile salmon growth rate (Trudel et al. 2008).

Mean June-July catch-per-unit-effort (CPUE) of juvenile Sockeye Salmon, Coho Salmon and Chinook Salmon decreased off the west coast of Vancouver Island (WCVI) in 2013 relative to 2012 and was at or below the 1998-2013 long-term average for these species (Fig. 20.1). Juvenile Chum Salmon showed the opposite pattern. The utility of using these CPUEs as early indicators of future adult returns is not clear, as CPUEs may be correlated with smolt production from south of WCVI, smolt survivals, or both.

In addition to juvenile salmon, we have also recorded catches of all the fish species that are brought on board the research or chartered vessels since 2005. Pacific Herring and Pacific Sardine are generally the dominant species of the fish pelagic communities off WCVI during daytime (Orsi et al. 2007). CPUE of Pacific Herring increased off WCVI in 2013, whereas the CPUE of mackerel (Chub Mackerel and Jack Mackerel) declined (Fig. 20.2). But perhaps the most surprising observation was the disappearance of Pacific Sardine off WCVI after their sudden returns to this area in 1992 (Hargreaves et al. 1994) (Fig. 20.2). The cause of this sudden shift in the species composition is unknown but may be linked to climate.

To explore this possibility, we performed a principal components analysis (PCA) on the CPUE of juvenile salmon, Pacific Herring, Pacific Sardine, and mackerel ($\log_{10}$ X+1 transformed, normalized to a mean of zero and standard deviation of one) for the 2005-2013 time period. The first two components explained 68% of the variance in the fish community composition (Fig. 20.3). Interestingly, juvenile salmon loaded primarily on the first axis, whereas the non-salmonids loaded on the second axis, with Pacific Herring and Pacific Sardines varying in opposite directions (Fig. 3). The PCA scores for the first axis were negatively correlated to the Pacific Decadal Oscillation (PDO) and sea surface temperature (SST) off Amphitrite Point on the west coast of Vancouver Island, but positively correlated to the North Pacific Gyre Oscillation Index (NPGO) (Fig. 20.4). The PCA scores for the second axis were positively correlated with the El Nino Southern Oscillation Index (ENSO) (Fig. 20.4). These results are consistent with previous studies that suggest that, in the California Current System, Pacific salmon are generally favoured by cooler temperatures, whereas Pacific Sardines and mackerel move further north during El Nino years (McFarlane et al. 2000).

Growth rates of juvenile Coho Salmon off WCVI decreased from 2012 and were below the 1998-2012 average in 2013 (Fig. 20.5). As our analyses indicate that the marine survival of WCVI Coho Salmon stocks is strongly correlated to their growth (Trudel et al. 2008), recent decreases in growth suggest that marine survival will be below to average for WCVI Coho Salmon returning in 2014 relative to 1999-2013.

Interestingly, juvenile Coho Salmon growth has generally been higher in even years than odd years since 2001, and this pattern continued in 2013 (Fig. 20.5). It is unclear what is the underlying mechanism generating this pattern. In marine waters of southern British Columbia, juvenile Pink Salmon are typically most abundant in even years (Irvine et al. 2014). However, they rarely show up off WCVI during summer, and are only present in moderate numbers during fall in even years. Moreover, they are thought to compete with juvenile Coho Salmon in the Strait of Georgia (Beamish et al. 2008).

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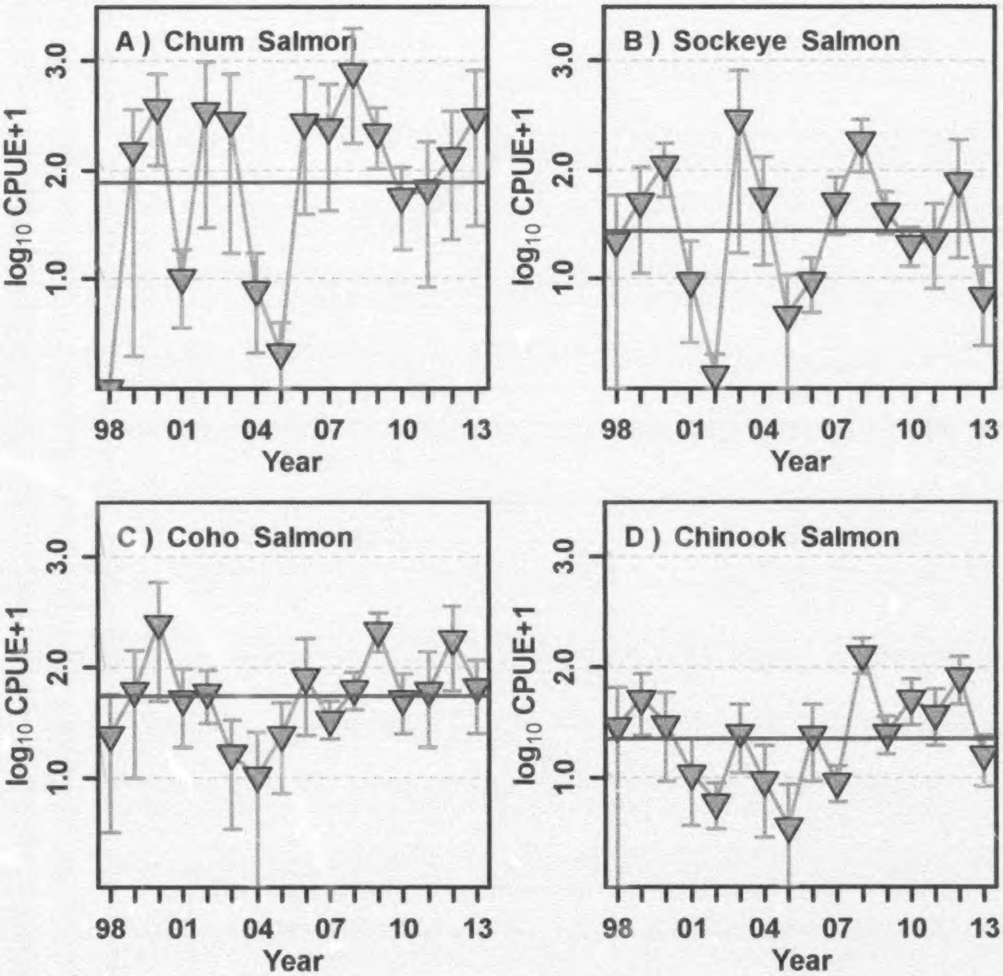

Figure 20.1. Catch-per-unit-effort (CPUE) of juvenile chum salmon, sockeye salmon, coho salmon, and Chinook salmon on the continental shelf off the west coast of Vancouver Island in June-July 1998-2013. The blue line represents the average value for the time series. Average CPUE and 95% confidence intervals were obtained by bootstrapping.

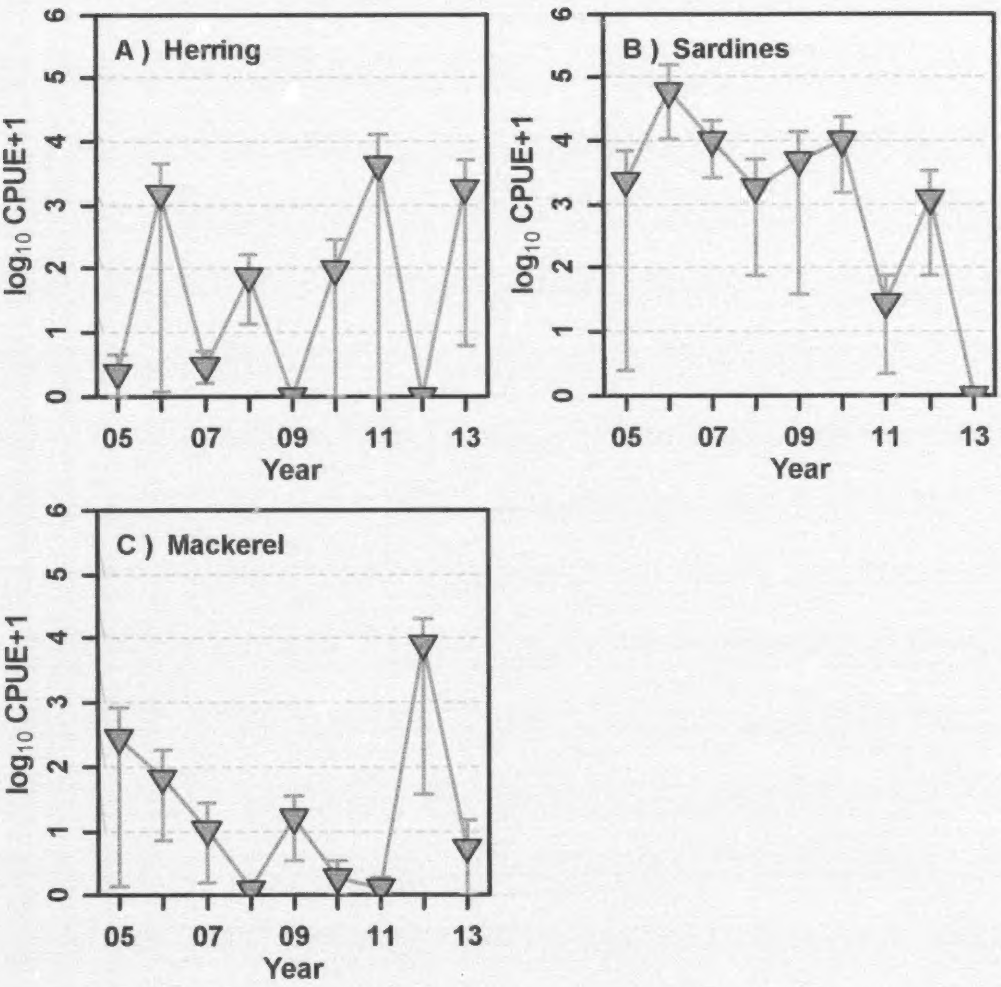

Figure 20.2. Catch-per-unit-effort (CPUE) of Pacific Herring, Pacific Sardine, and mackerel (Chum Mackerel and Jack Mackerel) on the continental shelf off the west coast of Vancouver Island in June-July 2005-2013. Average CPUE and 95% confidence intervals were obtained by bootstrapping.

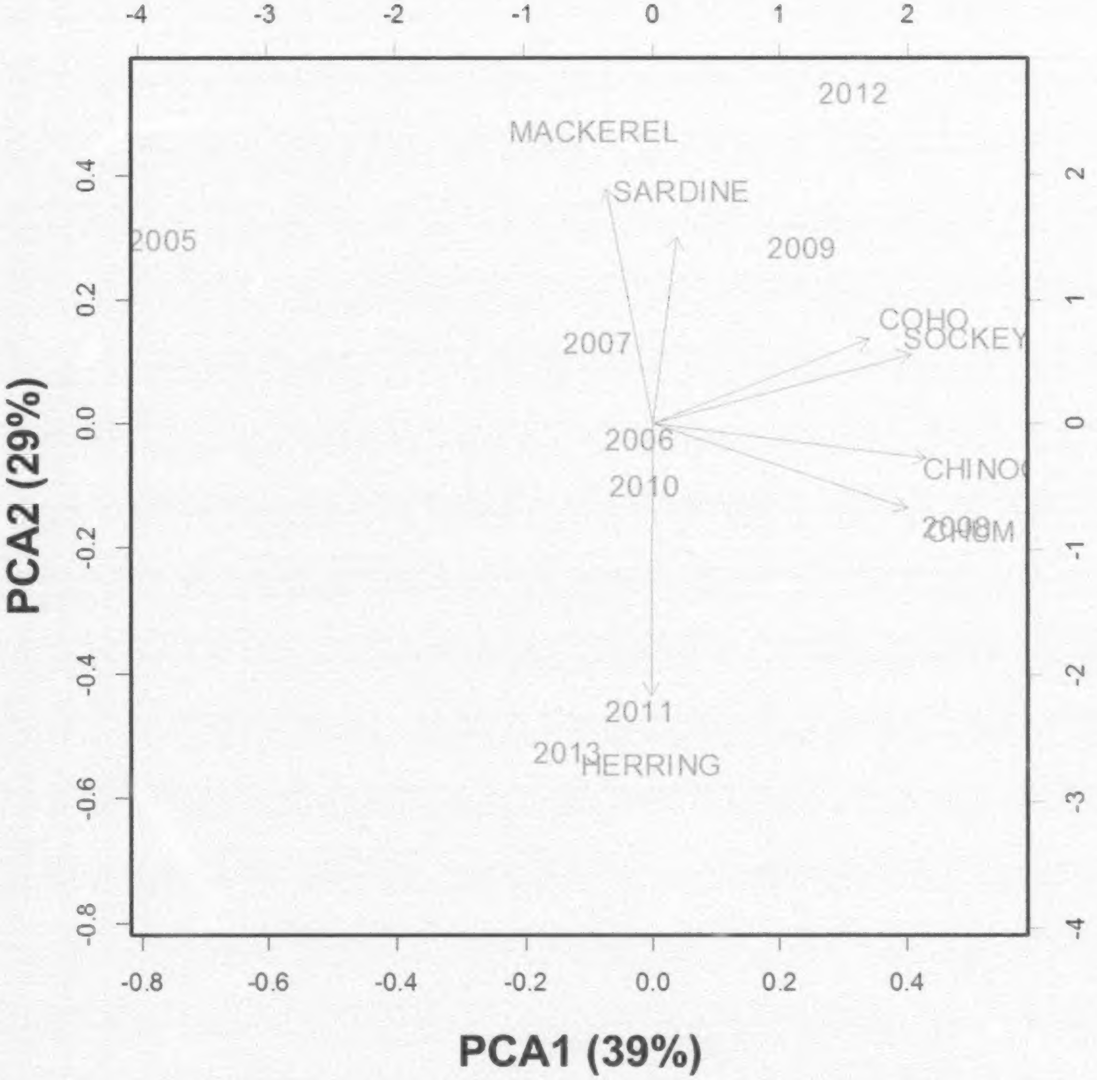

Figure 20.3. Principal components analysis of the dominant fish species caught in the pelagic waters off the west coast of Vancouver Island in 2005-2013 during daytime. The species are: Pacific Herring, Pacific Sardines, mackerel, Chum Salmon, Chinook Salmon, Coho Salmon, and Sockeye Salmon.

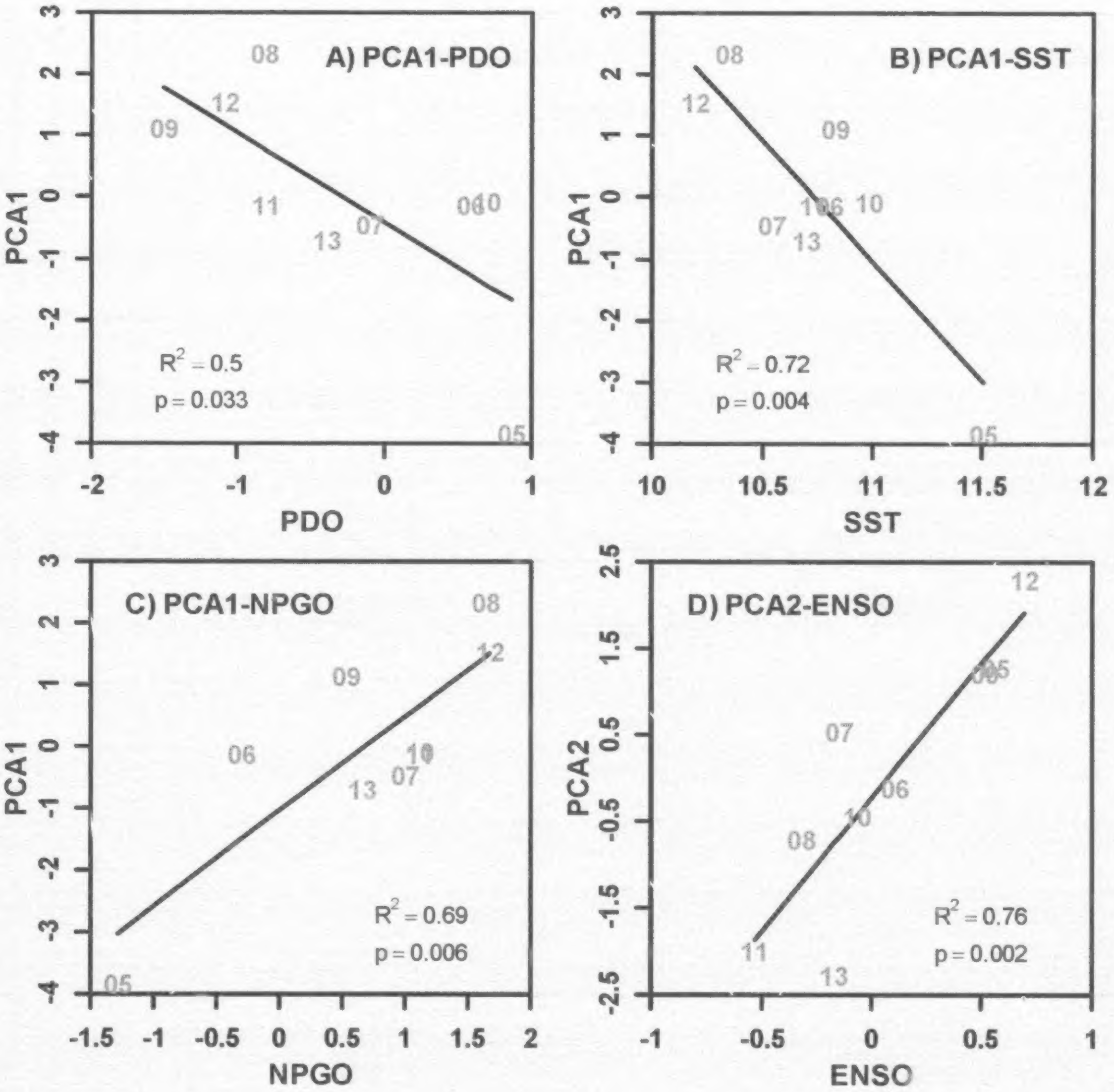

Figure 20.4. Correlation between principal components analysis (PCA) scores for the first two axes (PCA1 and PCA2) with various climate indices. PDO[1]: Pacific Decadal Oscillation (January-March average); SST[2]: sea surface temperature off Amphitrite Point on the west coast of Vancouver Island (March-July average); NPGO[3]: North Pacific Gyre Oscillation (March-July average); ENSO[4]: El Nino Southern Oscillation (March-June average).

[1] http://jisao.washington.edu/pdo/PDO.latest

[2] http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/data/amphitrt.txt

[3] http://www.o3d.org/npgo/data/NPGO.txt

[4] http://www.esrl.noaa.gov/psd/enso/mei/table.html

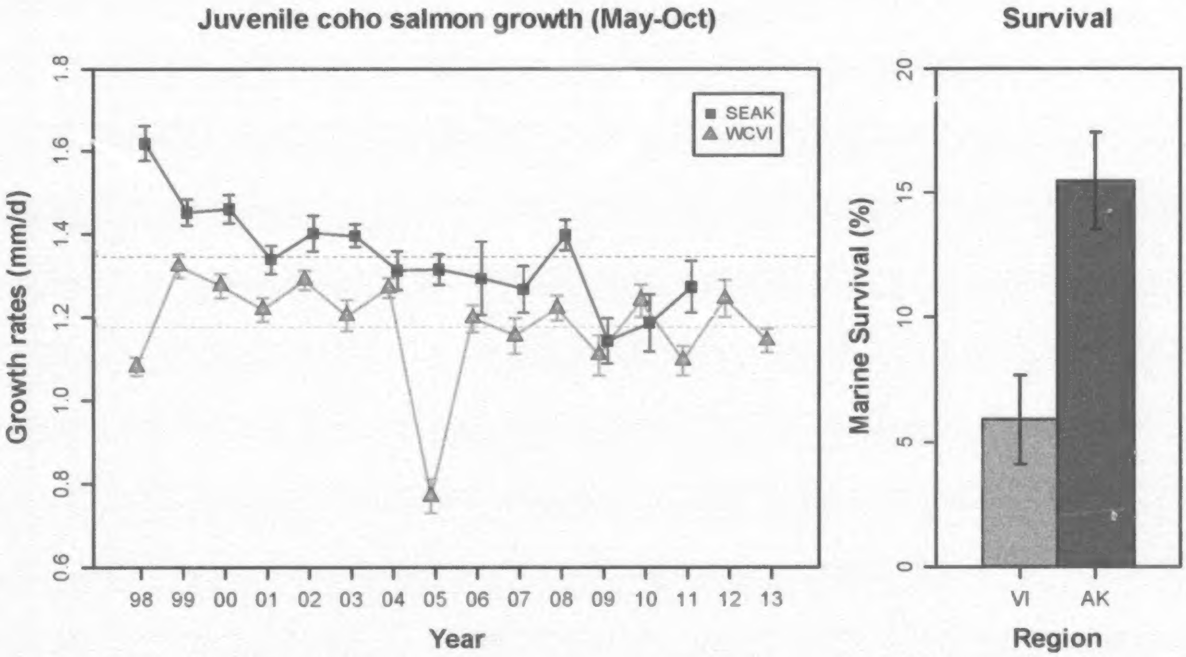

Figure 20.5. Growth rates (May-October) of juvenile coho salmon off the west coast of Vancouver Island (red triangles) and Southeast Alaska (blue squares). The blue and red dotted lines represent the 1998-2013 average values for Southeast Alaska and the west coast of Vancouver Island, respectively. The error bars are 2 times the standard error. Details on the procedure used to estimate growth rate are provided in Trudel et al. (2007).

21. Sockeye Salmon Indicator Stocks – Regional Overview of Trends, 2013 Returns, and 2014-2015 Outlook

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Studies by Mueter *et al.* (2002a, 2002b) and Pyper *et al.* (2005) suggest associations between Pacific salmon survival and coastal environmental variables (*upwelling index, sea surface temperature [SST], and sea surface salinity [SSS]*) are strongest at local spatial scales (<500 km intervals) for adjacent stocks and exhibit little to no co-variation at scales larger than 1000 km. Correlation scales for SST in summer most closely matched the correlation scales for salmon survival. Regional averages of SST appeared to be better predictors of survival than large-scale measures of SST variability (*e.g.* the Pacific Decadal Oscillation, Mueter et al. 2002b). Regional-scale variations in coastal SST's may reflect processes causing co-variation in survival rates of neighbouring stocks. Thus, neighbouring stocks may exhibit stronger similarities in survival and production variations than widely separated stocks. In addition, geographical overlap of salmon species during freshwater and early marine life stages appear more important in determining shared environmental effects on survival rates than life history differences between species (Pyper *et al.* 2005).

Comparisons of forecasts and observed returns of Sockeye Salmon for major rivers and fisheries in BC have been completed annually by DFO personnel for decades (Fig. 21.1). Given the observations above, production trends for major Sockeye populations or stock aggregates (*i.e.* "indicator-stocks") may reflect environmental changes and production trends for other salmon species originating from coastal-areas constituting separate production domains. Trend comparisons (1970-2013) among sockeye indicator-stocks permit the following generalizations:

- Return variations are large with maximum annual returns at 10-90 times minimum returns.
- Maximum returns for all Sockeye indicator stocks from the North Coast to the Fraser occurred in the early 1990s in association with the powerful 1989 La Niña event 2-3 years earlier. Similarly, a major La Niña event in 2008 was followed in 2010-11 by record to near-record returns of Vancouver Is. (Barkley), Fraser R. (Chilko), and Columbia R. (Okanagan) indicator stocks, dramatically reversing several years of sub-average, return trends (Figure 1).
- As anticipated earlier (Hyatt et al. 2011), southern Sockeye stocks, with sea-entry into the northern California Current upwelling domain (Okanagan, Barkley sockeye) exhibited rapid rebuilding to near record returns in 2009-2012 i.e. the decadal-scale, geographically-widespread, production-decline of sockeye from southeast Alaska to southern BC, reported by Peterman and Dorner (2012), is over.
- By contrast, Transboundary (Tahltan, Tatsamenie) and North Coast (Nass, Skeena) stocks continued a decadal-scale, sub-average return trend through 2013 with apparently little response associated with the 2008 La Nina (i.e. no major elevation of returns in 2010-13).
- Although there are several examples in each Sockeye indicator series for which observed returns diverged greatly from pre-season forecasts (Fig. 21.1), the latter commonly anticipate decadal-scale trends within each of their six coastal production domains of origin. Returns for all stocks in 2013 exhibited near average deviations from pre-season expectations.
- SST and ENSO indices in the Pacific remained negative to neutral in 2011-2013 so Columbia River (principally Okanagan) and west coast Vancouver Island Sockeye

(principally Barkley Sound) salmon marine survivals are likely to remain near their all-year average for the 2011-2013 sea-entry years (i.e. 2013-2016 adult return years). However, increased total returns of Barkley and Okanagan Sockeye are anticipated in 2014 (panels 5 and 6 in Fig. 21.1) due to increases in fry and smolt production associated with their 2011 lake-residence (i.e. 2012 sea-entry) year.

- Persistent, sub-average marine survivals exhibited by Sockeye indicator stocks originating from production domains on the Central Coast (Rivers & Smith Inlets), North Coast, and Transboundary (Tatsamenie, Tahltan) areas (Hyatt et al., unpublished observations) suggest total returns there will remain sub-average in 2013 through 2015.

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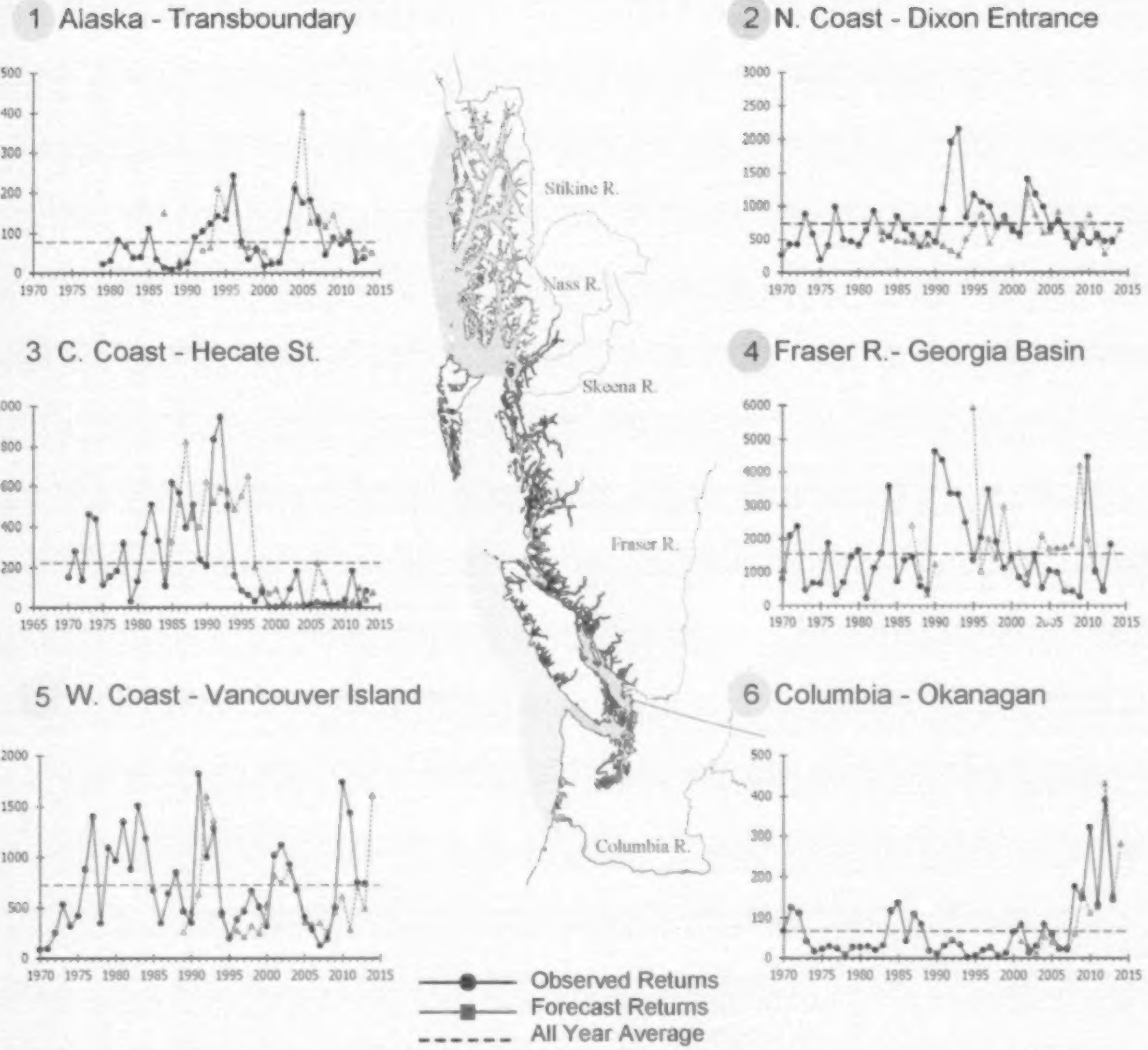

Figure 21.1. Trends in the total returns and forecasts for British Columbia Sockeye index stocks including: 1. Tahltan, 2. Nass, 3. Smith's Inlet, 4. Chilko, 5. Barkley Sound, and 6.Okanagan Sockeye salmon. Y-axis represents returns in thousands of fish.

22. Two North Pacific Right Whales Sighted in British Columbia in 2013

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Two unrelated sightings of North Pacific right whales, *Eubalaena japonica*, were made in Pacific Canadian waters in 2013 (Fig. 21.1). These sightings represent the first time this species has been confirmed in Canadian waters in 62 years, and likely the only time in the last 15 years that this species has been found south of Kodiak Island, Alaska in the eastern North Pacific Ocean (Scarff, J. pers. comm.). The eastern North Pacific population of right whale is considered to be the smallest population of whale in the world for which there is an abundance estimate and faces serious risk of extirpation (Wade et al. 2011a). As such, sightings of this species are extremely rare.

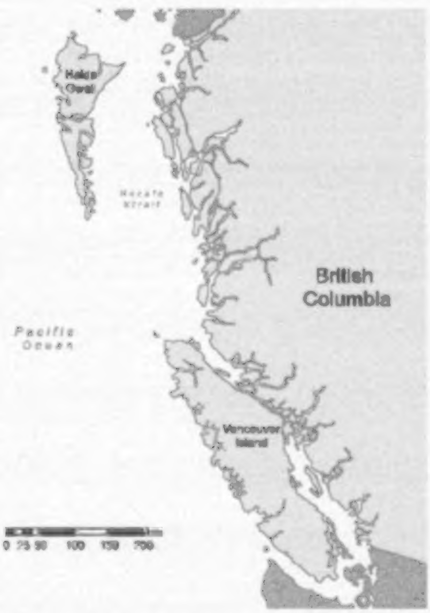

Figure 22.1. Locations (red dots) of the two North Pacific right whale sightings made in June (Haida Gwaii), and October (SW Vancouver Island), 2013.

Since 2002, the DFO Cetacean Research Program has conducted over 55,000 km of cetacean survey effort tracks from large-vessel platforms over shelf and off-shelf waters throughout Canada's Pacific Exclusive Economic Zone. These efforts, in addition to recent aerial survey effort since 2012 over the offshore waters of western Vancouver Island, have not located any right whales until these sightings in 2013. Similarly, no confirmed right whale detections have been documented in analyses of long-term passive acoustic monitoring data collected since 2006 by the Cetacean Research Program throughout British Columbia waters, though a dedicated focal analysis for right whale vocalizations has not yet been conducted.

This report is intended to inform the readers of the 2013 sightings, and provide general background information on the species in order to build context for these rare events.

19th and 20th Century Commercial Harvests

This once abundant species of baleen whale was hunted to near extinction in the North Pacific between 1835 and 1909, during which as many as 37,000 North Pacific right whales could have been killed (Scarff 2001). An international ban was placed on the hunting of right whales in 1935, after which illegal pelagic whaling by the Soviet Union continued and took an additional 529 animals which further reduced the population in the North Pacific to negligible numbers (Clapham & Ivashchenko 2009, Ivashchenko & Clapham 2012, Doroshenko 2000).

A total of 7 right whales were taken by whalers operating from coastal whaling stations in British Columbia between 1907 and 1951, 6 of which were taken in Canadian waters.

Distribution and Abundance

Examinations of historic whaling data from 19th century whaling catches suggest that the North Pacific right whale is likely divided into discrete western and eastern populations (Brownell 2001, NMFS 2013). Both populations are in serious risk of extirpation. Accurate population estimates do not exist for the western North Pacific population, though several hundred individuals are thought to exist there and sightings are made more regularly than in the east, albeit rarely (Brownell et al. 2001, Reilly et al. 2008). In contrast, the eastern North Pacific population has been estimated at only 30 animals (range 23-54) using multiple independent techniques (Wade et al. 2011a, Marques et al. 2011). Although the eastern stock estimate is based solely on the southeastern Bering Sea (SEBS) region, there is currently no reason to believe the entire eastern stock is any larger due to the paucity of sightings outside of the SEBS (Wade et al. 2011a, NMFS 2013).

North Pacific right whales were once distributed over the continental shelf, slope, and abyssal plains throughout much of the North Pacific, including off the coast of British Columbia (Sheldon et al. 2005, Townsend 1935, Maury 1852, Clapham et al. 2004, Scarff 1986). Small numbers have been detected regularly in the SEBS since 1996 (Goddard & Rugh 1998; Munger et al. 2008), and even smaller numbers have been documented on historical whaling grounds off Kodiak Island in the Gulf of Alaska (Wade et al. 2011b, Waite et al. 2003). Very few sightings have been made in the central Gulf of Alaska where a large majority of historical catches took place (Shelden et al. 2005). In winter in the eastern North Pacific, extremely rare sightings have been made off the Hawaiian Islands (Herman et al. 1980, Salden & Micklesen 1999), the Baja Peninsula (Gendron et al. 1999), and southern California (Caretta et al. 1994). In spring, a single individual was spotted travelling north 65 kilometers offshore on May 24, 1992 between Cape Elizabeth and Destruction Island, Washington (Rowlett 1994). Seasonal movements and migrations are poorly understood in this species, but there is some evidence for a northward movement in spring and summer, and a southbound movement in winter (Klumov 1962, Omura 1986, Clapham 2004).

In British Columbia, documented kills that occurred during the 19th century whaling efforts were concentrated around Haida Gwaii and Queen Charlotte Sound, including Hecate Strait, Dixon Entrance and over the shelf, slope, and abyssal plain west of Haida Gwaii (Townsend 1935, Maury 1852, Sheldon et al. 2005). The majority of these kills occurred between May and August. All but one of the 6 whales killed in Canadian waters by British Columbia whaling efforts in the 1900's were killed off the west and north coasts of Haida Gwaii, with one animal taken off northwest Vancouver Island. Recent habitat modeling suggests that the waters around Haida Gwaii and Queen Charlotte Sound could represent ideal seasonal feeding habitat for North Pacific right whales (Gregr 2011).

Foraging and Potential Prey

Right whales feed by swimming through prey laden water with their mouths open, filtering zooplankton from the water column with their long plates of baleen, a technique called 'ram' feeding (akin to a Basking Shark, though Basking sharks use their modified gills to filter, not baleen). Available evidence suggests that North Pacific right whales feed on late-stage calanoid copepods (Omura 1969, Gregr and Coyle 2009, Wade et al. 2007, Baumgartner et al. 2013), however some evidence suggests that euphausiids may also comprise a portion of their diet (Wade et al. 2011b, Nichol et al. 2002). On the SEBS shelf, Baumgartner et al. (2013) found that North Pacific Right Whales were targeting C5 stage *Calanus marshallae* that were foraging on re-suspended diatomaceous detritus above the ocean floor. Regional variations in habitat and oceanographic conditions as well as the physical limitations of their baleen filter likely play a large role in determining the availability of different species and stages of copepods to right whales (Gregr & Coyle 2009, Omura 1986). Indeed, the vast majority of right whales taken in the eastern North Pacific were killed in the central Gulf of Alaska, meaning the strictly on-shelf species (eg. *Calanus marshallae*), may not have been predominant prey items for a large portion of the historic population. Stomach contents examined from 13 individuals taken for scientific purposes by Japanese scientists in the eastern North Pacific in the 1960's found *Neocalanus plumchrus* in the stomachs of 3 animals killed in deeper waters off Kodiak Island, while *N. cristatus* was found in stomachs of 3 animals killed in off-shelf waters of the Bering Sea. Smaller quantities of other zooplankton species, including *Calanus marshallae, Euphausia pacifica* and *Metridia spp.* were also found in the stomachs (Omura 1969). Stomach contents of the right whale killed off Vancouver Island in 1951 reportedly contained 'red feed' which in most cases was interpreted as euphausiids (Nichol et al. 2002), however, copepods can also have a red hue in stomach contents making a positive interpretation of 'red feed' difficult in this case. More recently, right whale sightings off Kodiak Island were found to be located in areas with the highest local densities of zooplankton (measured from active acoustic backscatter) comprised predominantly of *Neocalanus cristatus* and *Euphausia pacifica* (Wade et al. 2011b). Right whales in the North Atlantic feed primarily on *Calanus marshallae*, and may require very high densities of prey to meet daily energetic requirements (>3000/m^3), which they exploit at depth or at the surface (Baumgartner et al. 2003). Compared to North Atlantic right whales, there have been very few opportunities for researchers to observe foraging in North Pacific right whales.

British Columbia Sightings, 2013

The first sighting in 2013 was made on June 9th by Cetacean Research Program (CRP) researchers during a whale survey aboard the CCGS *Arrow Post*. The sighting was of a single whale (Fig. 22.2) on the shelf slope 8 nautical miles off the northwest coast of Haida Gwaii between Port Louis and Frederick Island (53 37.487N/133 17.217W). The animal was subsequently re-located on June 12 and June 13 within 12 nautical miles of the original sighting location, still on the shelf slope. The researchers spent a total of 17 hours observing the animal, which allowed for the collection of identification photos as well as genetic and scat samples. Each day, the whale's predominant behaviour was feeding on visibly dense aggregations of zooplankton prey at the surface. On two days, small samples of prey were collected at the surface using a fine-meshed net about 30 meters behind the feeding whale. These were identified as late-stage *Neocalanus plumchrus* (C5: n=13; C4: n=1). A sample of scat collected at the surface awaits visual and genetic identification of prey species.

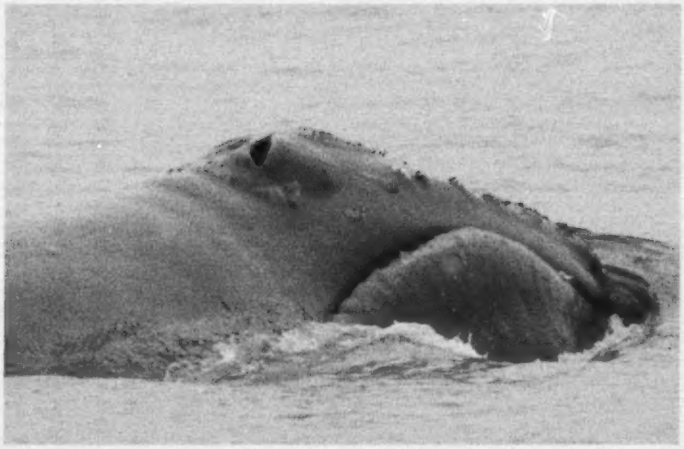

Figure 22.2. Photo of the North Pacific right whale sighted off of Haida Gwaii in June 2013. Note the strongly arched lower mandible, and roughened patches of skin on rostrum (callosities). Photo credit: Graeme Ellis.

The second sighting of 2013 was made on October 25 at Swiftsure Bank, Southwest Vancouver Island (48 31.041N/124 52.338W), by CRP field technician, Brian Gisborne. The animal was found amongst a large aggregation of humpback whales, which is not an uncommon scenario in other parts of the North Pacific (Wade et al. 2011b, Herman et al. 1980). To an extent, the whale seemed to be socializing with the humpbacks at the surface for at least a portion of the encounter. The animal was re-located the following day in the same area on Swiftsure Bank by Brian and a team of CRP researchers. Approximately 8 hours were spent observing and photographing the whale over the two days. No surface feeding was documented during this encounter, though occasional feeding at depth could not be ruled out. Identification photographs of the animal were collected, which confirmed this was a different individual from the animal sighted in June.

Although one should not infer too much from just two sightings, it is curious that two sightings of two unique individual right whales were sighted in the same season after 62 years without a single confirmed sighting in Canadian waters. This, combined with recent reports from American researchers stating they have also documented acoustic detections of right whales off their west coast in 2013, certainly indicates that these sightings and detections were likely not a coincidence. Anomalous oceanographic and climatic conditions were observed in 2013 in the Gulf of Alaska (see other reports in this collection for details), which opens the possibility that the occurrence of these sightings could have been influenced by variations in large-scale conditions. Also, higher than average levels of subarctic copepod biomass along the shelf break in British Columbia was also documented in 2013, which indicates that right whale prey was abundant, at least during the June 2013 sighting.

Acknowledgements

The sighting and data collection in June would not have been possible without the hard work and dedication of Captain Gary Coup and officers and crew of the CCGS Arrow Post. The countless hours of survey work by Brian Gisborne off the southwest coast of Vancouver Island made the October sighting possible. Graeme Ellis and Robin Abernethy were integral to sighting follow-up efforts.

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Strait of Georgia

23. Spring Phytoplankton Bloom in the Strait of Georgia

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The timing of the spring phytoplankton bloom in the Strait of Georgia is highly variable, ranging from late February to mid-April. Changes in the timing have been related to the success of herring larval recruitment (Schweigert et al., 2013) and studies in a nearby fjord suggest it may affect the zooplankton species composition (Tommasi et al., 2013). In this well stratified, mid-latitude system, the timing is controlled by the light availability to the phytoplankton which is in turn controlled by the incoming light (cloud fraction decreases this) and by the depth over which the phytoplankton are mixed (wind increases this).

Historically, observations with the high temporal resolution necessary to identify the timing of the bloom have been few. A computer model coupling the physics and lower trophic levels in the Strait of Georgia has been developed and can successfully model the timing of the spring bloom (Collins et al, 2009) which has allowed a hindcast of the timing since 1969 (Allen and Wolfe, 2013).

However in 2013, observations of the timing of the spring phytoplankton bloom were many and included *in-situ* observations made from the CSS Vector in mid-April 2013 (Peña and Nemcek, this issue), ferry-box observations from the Queen of Alberni (on the Tsawwassen-Duke Point Line, (Wang & Pawlowicz, personal communication) and on the Spirit of Vancouver Island (on the Tsawwassen-Swartz Bay Line, Gower, this issue), a mooring attached to the weather buoy at Halibut Bank (ibid) and satellite data (*ibid* and Costa et al., this issue). The full-depth and numerous stations sampling done from the Vector cruise in April showed that the spring bloom must have occurred at least a week before the cruise, putting a firm late bound on the bloom of April 2, 2013 (Peña and Nemcek, this issue). The weather buoy at Halibut Bank showed a bloom around March 10 (Gower, this issue), whereas the ferry-box on the Queen of Alberni showed a bloom, all along its path, between March 27 and April 4 (Wang & Pawlowicz, personal communication). Satellite data considering the central Strait of Georgia, showed a bloom between March 30 and April 7 (Costa et al., this issue). The difference between the Halibut Bank buoy and the ferry box is intriguing (Fig. 23.1); are there local blooms at Halibut Bank?

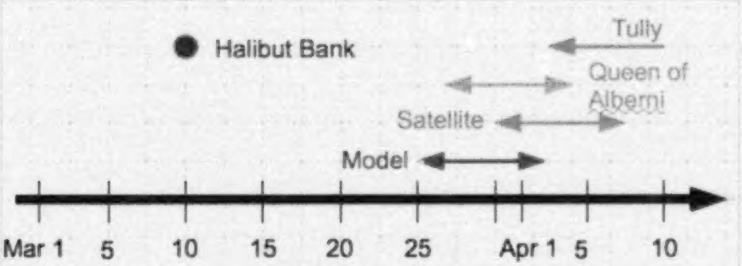

Figure 23.1: *A time series plot showing spring bloom timing according to a variety of measurements compared to the model derived timing. Note that in-situ observations made from the Vector give a late bound, not a range.*

2013 Spring Bloom According to the Model

February and early-March of 2013 were windy. These winds kept the phytoplankton biomass low. A switch to nice weather in late March (both calm and low clouds) allowed a rapid spring bloom which, according to the model peaked on March 29±4 days (Fig. 23.2). Compared to most years, the model suggests less biomass before the bloom and a rapid bloom peak. Aragonite saturation state (Ω_a) is considered a relevant biological indicator for organisms that form calcium carbonate shells such as shellfish (Raven et al., 2005, Fabry et al., 2008). When $\Omega_a < 1$, such as before March 7, 2013 (Fig. 23.2), the seawater is corrosive to $CaCO_3$ in the absence of organic protective layers.

From the model hindcasts, spring blooms from 2006-2013 were all later than March 28 (Allen and Wolfe, 2013), meaning we have been in an 8 year period of stable, late spring blooms (Fig. 23.3).

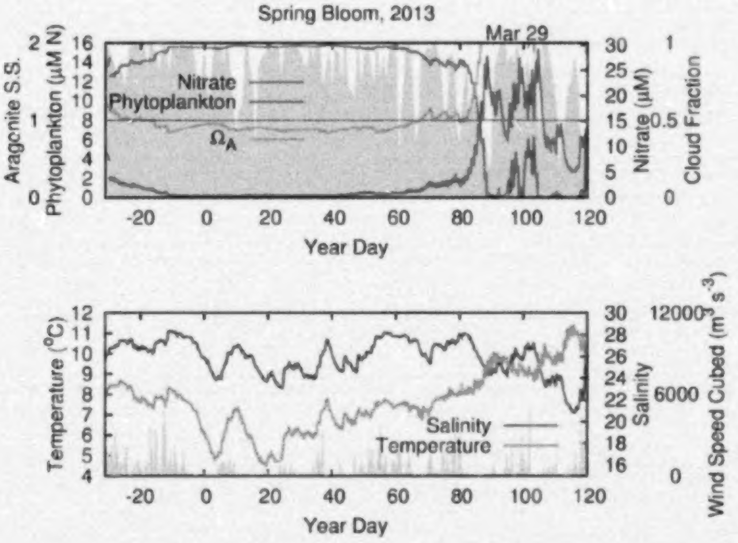

Figure 23.2. *Hindcast of the 2013 Spring Bloom and related conditions in the Strait of Georgia. The lower panel shows temperature (in red) and salinity (in blue) averaged over the upper 3 m of the water column; in grey is the wind-speed cubed which is directly related to the strength of the mixing. One can clearly see the mixing associated with the storm about day 35; salinities increase as deeper high salinity water is mixed into the surface waters and temperatures also increase as deeper warmer water is mixed upward. The top panel shows phytoplankton biomass (in dark red), nitrate (in green) and aragonite saturation state (in teal); in grey is the cloud fraction averaged over the day. One can see the influence of low wind, low cloud periods such as that after day 80. Here phytoplankton biomass steadily increases and nitrate decreases. The aragonite saturation state rapidly increases during the rapid growth phase (day 80-90) as phytoplankton take-up carbon. The 2013 spring bloom (Mar 29) was a bit later than the mean (Mar 21) because of the windiness of February and March. Plots span the period Dec 1, 2012 to Apr 30, 2013.*

The 2014 Spring Bloom prediction from the model

Winds were reasonably strong through the winter, but good weather in early March seemed to suggest a bloom would occur in third week of March around the median bloom date. However, a severe wind storm on Mar 17 mixed the water column down to 26 m and delayed the bloom. As of this writing (March 28) the bloom is expected within days, unless there is another strong storm.

Details of the coupled-biophysical Model

The model is a vertical-mixing layer model forced by observed winds at Sand Heads, observed air temperature, humidity and cloud fraction at Vancouver International Airport (YVR), Fraser River flow at Hope and Englishman River flow at Parksville (Environment Canada, 2012 a & b). The latter is multiplied by 55 to represent all river flows into the Strait other than the Fraser River. The physical model is based on the Large et al. (1994) KPP-model with an estuarine circulation model added (Collins et al., 2009). To model a spring bloom, only a simple nitrate-diatom biological model is used. The diatom growth parameters are taken from the literature based on the first phytoplankton to bloom in the Strait (*Thalassiosira* spp.). The model zooplankton concentration was taken from observations (Sastri and Dower, 2009) and the model was tuned by adjusting the phytoplankton growth rate (Allen and Wolfe, 2013) within the range measured in the laboratory. The model was tuned, within 4 days, for the spring blooms of 2002-2005 for which detailed observations were made as part of the STRATOGEM project (Allen and Wolfe, 2013). A carbon module that models dissolved inorganic carbon and total alkalinity has been added to the model and allows estimation of aragonite saturation state (Moore-Maley, in prep.).

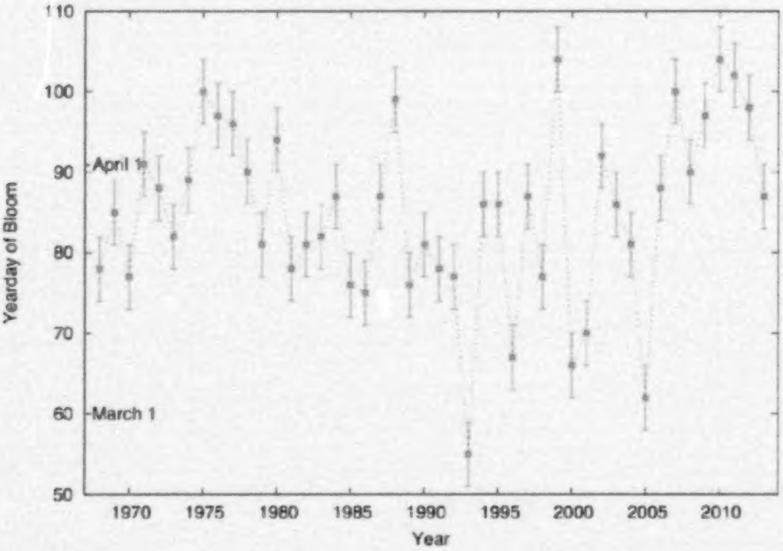

Figure 23.3. *A time-series showing 2013 bloom in context of previous years. Note the period of stable late blooms since 2006.*

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24. Strait of Georgia Spring bloom timing 2013

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In 2013, timing of the bloom was monitored (Gower, IOS) using satellite imagery, and recording fluorometers on the Halibut Bank buoy and on the Spirit of Vancouver Island ferry (Tsawwassen to Swartz Bay route). Fluorometer data are also available from Ocean Networks Canada from the Queen of Alberni ferry on the Tsawwassen to Duke Point route. Satellite imagery is Level 1 FLH, which gives the clearest and most frequent images of bloom development. In 2013, the Halibut Bank and Spirit of Vancouver Island fluorometers agree with satellite imagery in showing an extensive bloom in the mid and southern Strait starting on about March 10 2013 (day 69).

The summary of start dates for the central Strait (south tip of Texada Island down to Active Pass) for years 2003 to 2013 is shown in Fig. 24.1. Dates from Gower, IOS are compared with dates from Maycira Costa (Department of Geography, UVic) using Level 2 chlorophyll values from MODIS with atmospheric correction refined to local conditions, and Susan Allen (Earth and Ocean Sciences, UBC) using a model based on wind, fresh water run-off and insolation. Mean and standard deviations of day numbers are 60 ± 10 for Gower for years with seeding of phytoplankton from adjacent inlets, 84 ± 9 for Gower for years without seeding, 93 ± 9 for Costa and 91 ± 12 for Allen. Satellite images are designed to show the optical changes due to increased concentrations of near-surface phytoplankton and would be expected to give dates a few days earlier than the model, which is tuned to the time of exhaustion of nitrogen at the end of this first growth.

In 2013, Halibut Bank fluorometer gives a clear date for that one location (Fig. 24.2) and satellite images show the spatial patterns (Fig. 24.3). The date is confirmed by data from the Spirit of Vancouver Island (Fig. 24.4). The image on March 8 (Figure 3) suggests that the bloom may have started in Howe Sound and "seeded" the Strait shortly thereafter. A fluorometer time series (not shown here) at Egmont, B.C., shows water with high-chlorophyll flowing from Sechelt Inlet between days 50 and 60, but then low values until about day 90. This indicates the possibility of some seeding from Jervis/Sechelt Inlets, but satellite imagery (Fig. 24.3) shows no evidence of a "Dragon" bloom in the Malaspina area as in 2004, 2005, 2007, 2008 and 2009 (Gower et al. 2013). This year is therefore listed as "without seeding."

Data from the Queen of Alberni ferry show low chlorophylls until about March 29 (Figs. 24.5 and 24.6), but the data quality is flagged as "unknown." Oxygen data from the same ferry (Fig. 24.7) suggest a significant increase in production in the Strait after March 11 with a further increase after about March 25. Satellite imagery (level 1 FLH, Fig. 24.3) shows high chlorophyll along the ferry track between Duke Point and Tsawwassen from March 8 into April, with clear images on 8, 9, 18, 21, 22, 23, 28, 29, 30, 31 March. These show high chlorophyll along this ferry track on all these dates. It is not clear why data from this ferry should show low chlorophyll from March 8 to March 29. Image data used by Maycira Costa are 8-day composites of reprocessed MODIS images. Standard MODIS products (4 km, Level 2 chlorophyll and fluorescence) from the NASA Giovanni system for the area 49.2 to 49.5N, 123.6 to 124W show the first high signal in the period 6 to 13 March. Fluorescence then stays high through March, but the chlorophyll value is low in 14-29 March and much higher in 30 March to 6 April.

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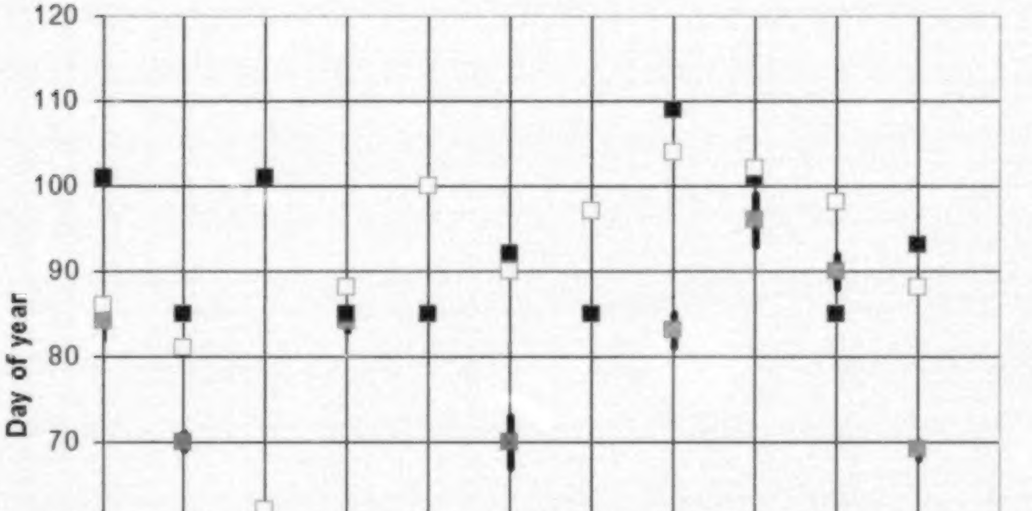

Figure 24.1. Spring bloom start dates for the central Strait of Georgia, derived from MODIS satellite using Level 1 FLH (and fluorometers starting in 2009) separating years with seeding from Jervis and Sechelt Inlets (Gower, green) and years without such seeding (Gower, red), MODIS satellite using processing adapted to local conditions (Costa, black) and model predictions (Allen, open red). Error bars shown represent effects of data gaps due to cloud. Estimated errors for Costa and Allen data are plus or minus 4 days in all years.

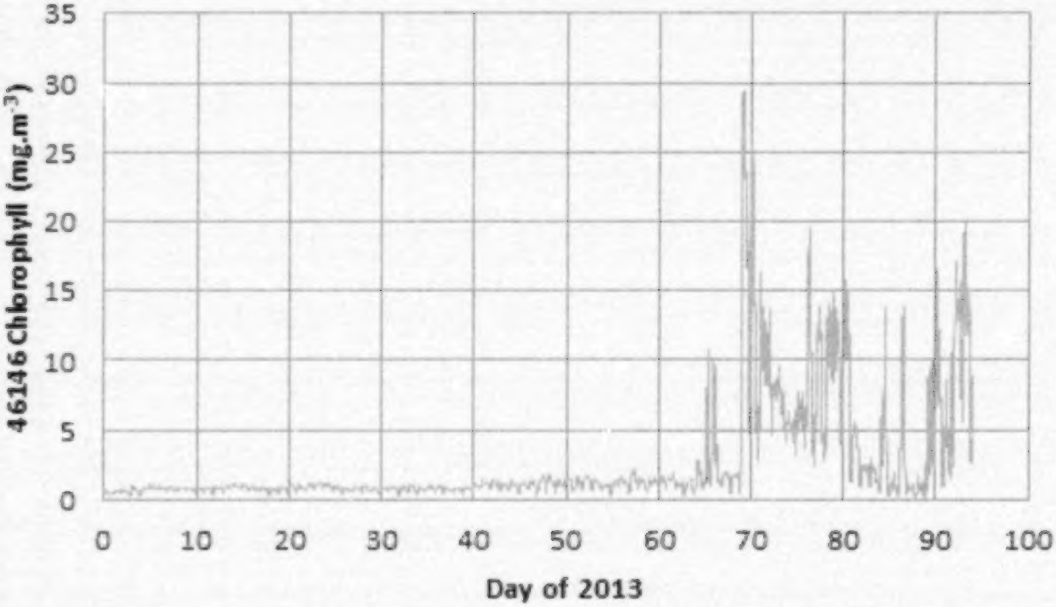

Figure 24.2. Halibut Bank chlorophyll time series for spring 2013 (analysis by Stephanie King). Day 69 is 10 March. MODIS satellite imagery (Fig. 24.3) shows the first wisp of possible bloom on day 62, with Halibut Bank shown to be in a low-chlorophyll area on day 67.

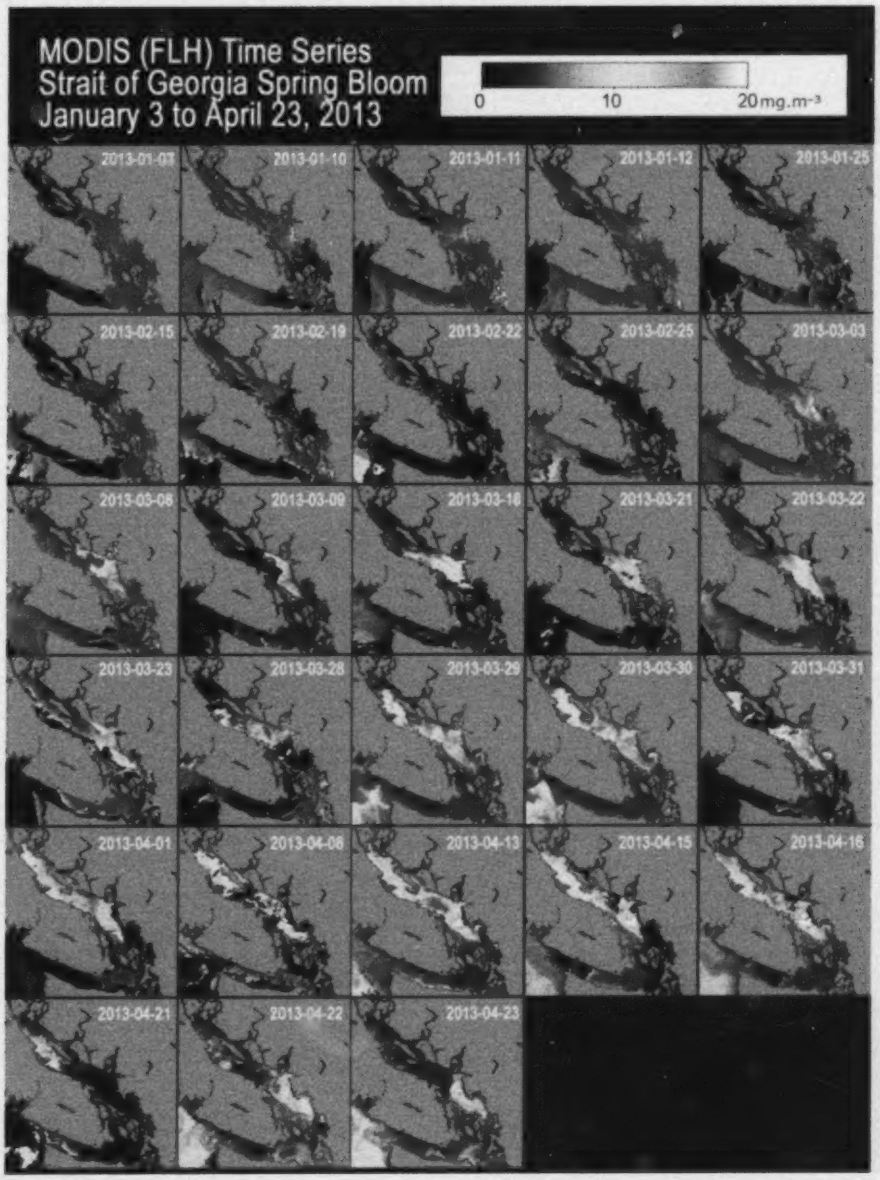

Figure 24.3. MODIS satellite imagery (Level 1 FLH) of the Strait of Georgia and Juan de Fuca Strait on cloud-free and partially cloud-free days in January to April 2013. Images show a first wisp of bloom on March 3 (day 62) with more extensive areas of bloom on March 8 and 9 (days 67, 68) and from then on into April, with bloom in the northern Strait from about March 29. Days shown are 3, 10, 11, 12 and 25 January, 15, 19, 22, 25 February, 3, 8, 9, 18, 21, 22, 23, 28, 29, 30, 31 March and 1, 8, 13, 15, 16, 21, 22, 23 April. Important dates are 3 March (first wisp of bloom near Fraser plume), 8 March extensive bloom including along ferry track, but not at Halibut Bank, 9 March, partly confirming 8 March, but with some cloud, 18 March to 16 April extensive bloom in central Strait. First bloom in the northern Strait is seen on 28 March.

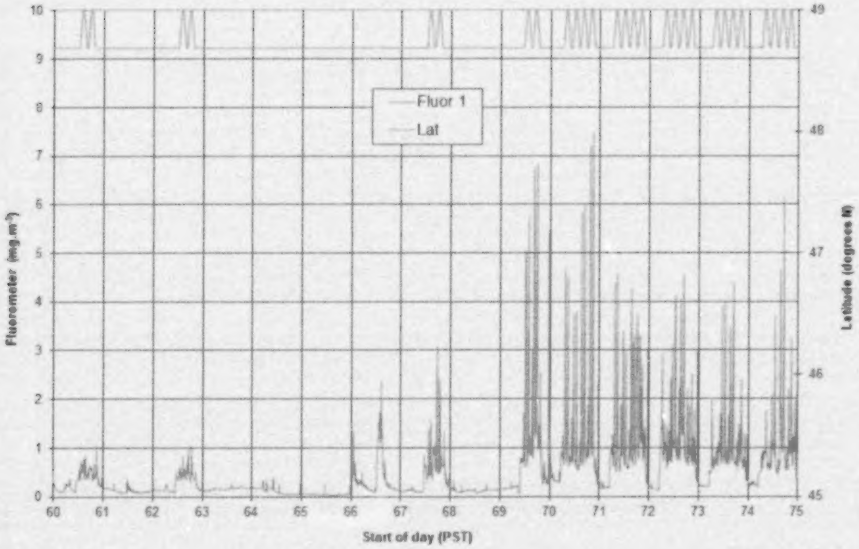

Figure 24.4. Fluorometer data from the Spirit of Vancouver Island ferry, Tsawwassen to Swartz Bay, confirm low values up to about day 69 (10 March) and high values thereafter. The high values are in the Strait of Georgia, not among the Gulf Islands. The ferry was "number 2 boat" operating for only two sailings on each of Friday and Sunday until day 70, as shown by the latitude plot (right axis) at the top of the figure.

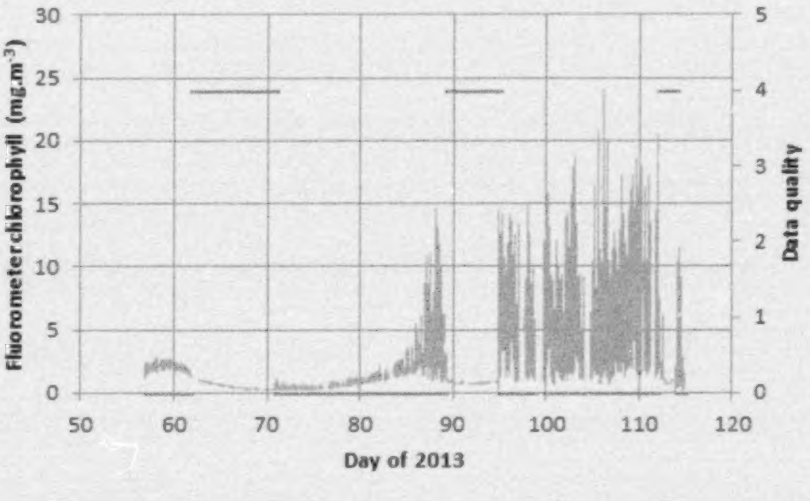

Figure 24.5. Fluorescence data from a WetLabs "puck" sensor on the Queen of Alberni ferry near the start of 2013 suggests start of spring bloom at about day 88, with no sign of the high values after day 69 as seen in Figures 2 to 4. Data quality is flagged (red, right axis) as bad (code=4) or unknown (code=0). The apparent drifting baseline before day 87 may indicate fouling.

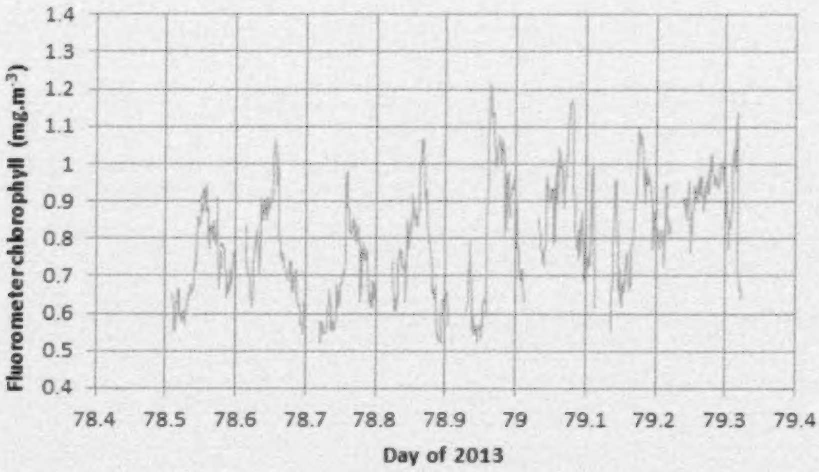

Figure 24.6. Fluorescence data from the Queen of Alberni ferry on day 78 (UT), 19 March 2013 show a consistent pattern as the ferry makes four repeat tracks in the day, but the low values disagree with the earlier start to the bloom shown by Figures 2 to 4, and with the oxygen measurements in Fig. 24.7.

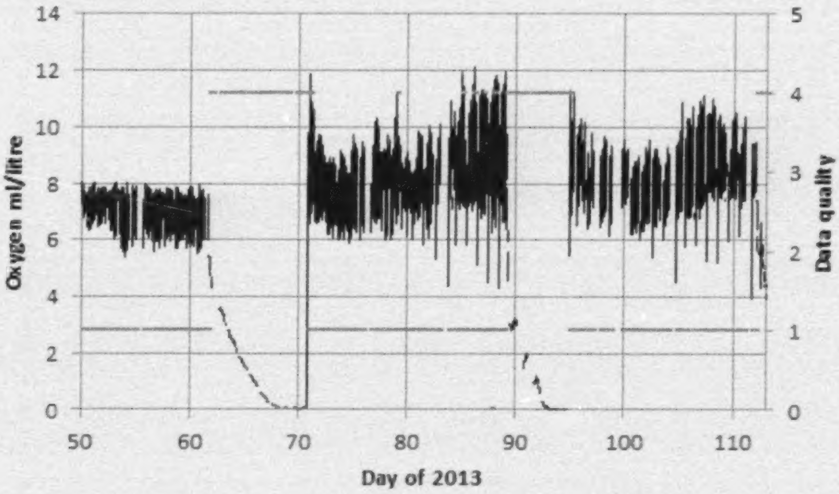

Figure 24.7. Oxygen data from an Anderaa Optode on the Queen of Alberni ferry shows values close to and below saturation before good data ended on day 62, and significant supersaturation after good data restarted on day 70 suggesting start of a bloom before this date. Oxygen continues increasing after about day 84 suggesting further growth. Data quality is flagged (red, right axis) as good (code = 1) with two bad periods as shown.

25. Spatial-temporal phytoplankton bloom initiation in the Strait of Georgia derived from MODIS imagery: 2002-2013

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Satellite remote sensing offers a synoptic, cost effective, and repeatable method of deriving ocean surface chlorophyll *(Chl)* concentrations as a proxy for phytoplankton biomass, in place of traditional ship-based methods. This report includes the analysis of a 12-year time series of MODIS-derived bloom initiation data for three sub-regions of the Strait of Georgia (SoG). Future work will include analysis of the time series data of MODIS-derived bloom metrics and juvenile sockeye indices for the SoG (Carswell et al., 2012).

Image data (level 1a) were accessed from NASA's OceanColor web portal, and processed in the SeaDAS (Seawifs Data Analysis System) environment. All available good quality MODIS-Aqua images (n=3704, entire data base 2002-2013) were processed. The images were first atmospherically calibrated according to the Management Unit of the North Sea Mathematical Models (MUMM) and shortwave infrared wavelengths (SWIR) methods (Komick et al., in preparation). The derived Aerosol Optical Thickness (AOT) at 443nm from a sub-set of images acquired in 2006, 2007, and 2008 (n= 176) was compared with match-up data from the AERONET system from Saturna Island (R^2=0.67). Second, the empirical Ocean Color version 3-MODIS (OC3M) *Chl* algorithm (Komick et al., 2009) was validated according to *in situ* data from the DFO Institute of Ocean Sciences database and our own HPLC measurements (R^2=0.84; slope 0.92; n=120) for the SoG.

Third, all *Chl* images were spatially binned and then temporally binned to derive mean 8-day *Chl* concentrations. Weekly 8-day *Chl* concentrations were derived for three sub-regions located in the north, central, and south SoG (Fig. 25.1). For each sub-region, median *Chl* was extracted as a robust measure of the central tendency of the population. From that, outliers were identified as *Chl* values higher than 2.5 of the Median Absolute Deviation (MAD). Timing of bloom initiation was defined as the yearday (+/- 4 days) where *Chl* concentrations were greater than the annual median plus 5% (not considering January and February) or the yearday of the first *Chl* estimate greater than 6.0 mg m^{-3} (similar to Schweigert et al., 2013 and Siegel et al., 2003). Yearday bloom initiation for each sub-region is presented in Fig. 25.2.

Time of bloom initiation varied among the three different sub-regions. For the central sub-region, the time series analysis of the MODIS Aqua imagery shows that spring bloom initiation generally happened from mid-late March to early-mid April. The latest spring bloom initiation happened in 2010 in mid-April, and the earliest in 2004, 2006, 2007, 2009, and 2012 in late March. However, review of the weekly February images from 2005 revealed that a much earlier bloom may have happened in February (due to the present methodological approach, this event was not captured). Bloom initiation in 2013 followed the trend of the majority of the previous years: late March to early April; specifically, from March 30 to April 7. This period coincides with the March 29 +/- 4 days model bloom estimates by Allen et al. (this issue). Average (all the runs of the day - keep in mind diurnal variations) *Chl* fluorescence observations from the Ocean Networks Canada ferry box on the Queen of Alberni ferry (Fig. 25.3) also show an increase of *Chl* concentrations in central SoG by the end of March 2013. *Chl* reached values of approximately 12.0 mg m^{-3}, 11 mg m^{-3}, and 6 mg m^{-3} in the following days. HPLC-derived *Chl* in water samples collected along the same ferry route in March 28 resulted in 5.04 mg m^{-3}; in April 11, *Chl* was about 5.17 to 8.87 mg m^{-3}.

For the south and north sub-regions, the imagery time series shows that spring bloom initiation on average happened about 2 weeks after the start of the bloom in the central sub-region. However, in the last 3 years the bloom has started 1 month later in the south. Time of bloom initiation between central and north sub-regions tends to coincide, except, for example, in 2012 when the bloom in the north happened more than a month later than in the central sub-region. The differences in spring bloom initiation among the three sub-regions needs further investigation. Determining inter-annual relationships between the timing/magnitude/duration of the spring bloom and the residence/condition of juvenile salmon entering the SoG from nursery lakes may be paramount for ecologically based fisheries management. Our approach applied to a 12-year time series of data will help to understand these relationships.

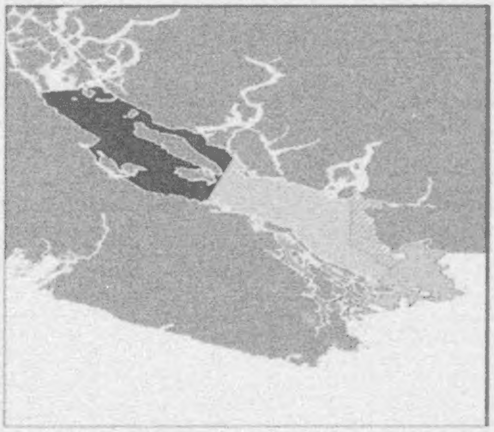

Figure 25.1. Sub-regions of the Strait of Georgia analysed in this study. Red: North; Blue: Central; Purple: South.

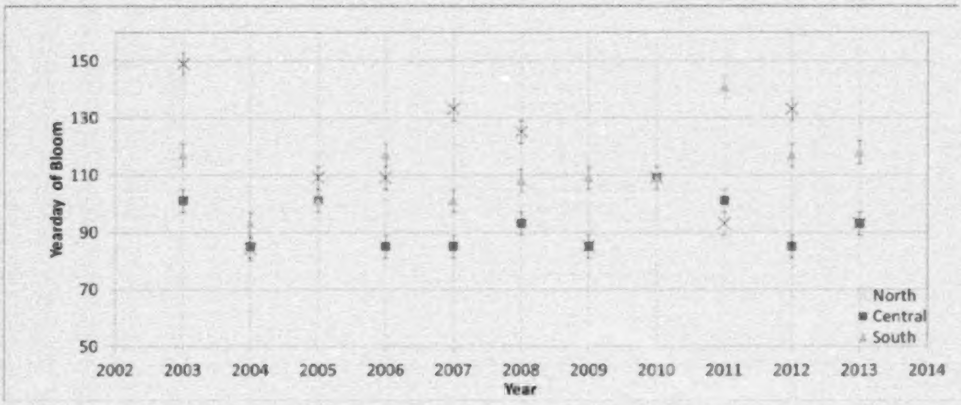

Figure 25.2. MODIS-Aqua derived time-series of spring bloom initiation dates in the Strait of Georgia.

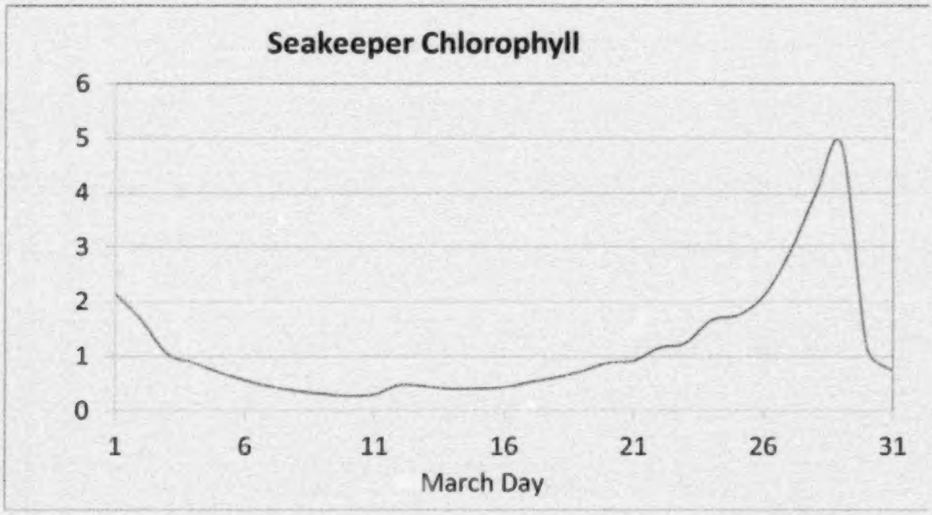

Figure 25.3. Chlorophyll measurements from the SeaKeeper system in the Queen of Alberni ferry: March 2013.

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26. Phytoplankton in the Strait of Georgia

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Concentrations of nutrients and chlorophyll-*a* ("chl", an indicator of phytoplankton biomass) are measured on 5-day cruises 3 times a year in spring (April), summer (June), and fall (Sept. to early Oct) along a 20-station transect in the Salish Sea (Fig. 26.1). Although they are a snapshot of annual conditions, they have been carried out for many years providing information on seasonality. In general, upper layer (0-10 m) chl concentrations in the Strait of Georgia are highly variable in spring, being >15 mg m^{-3} during phytoplankton bloom events (mid Feb. to April), low during the summer and fall (1-4 mg m^{-3} on average), and lowest (<0.5 mg m^{-3}) during winter. In comparison, no spring bloom events have been observed in Juan de Fuca Strait and chl concentrations there are significantly lower (<3 mg m^{-3}) than in the Strait of Georgia in spring, perhaps due to strong vertical mixing. On average, similar low chl values are found at other times of the year in both regions but they are more variable in Juan de Fuca Strait.

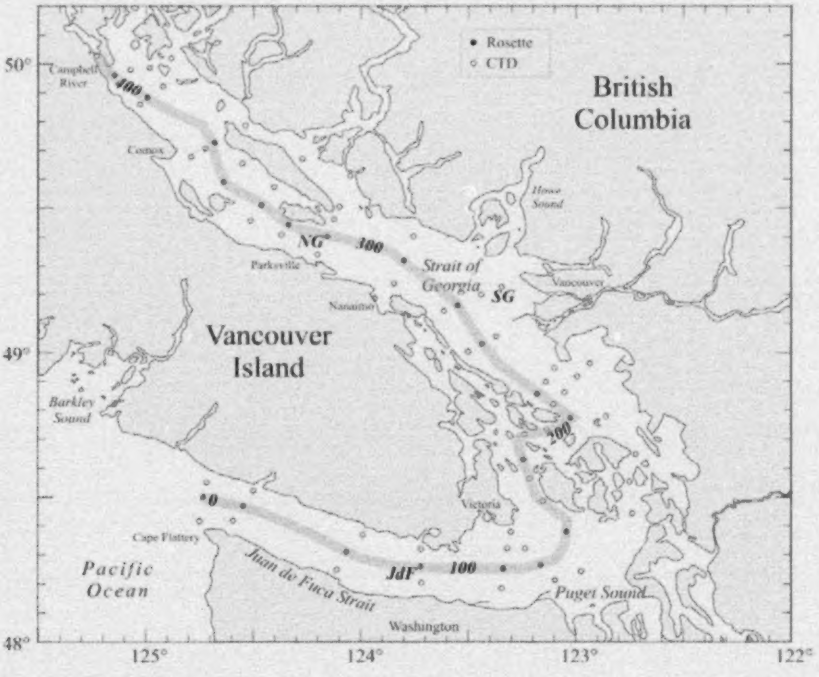

Figure 26.1. Location of sampling stations in the Juan de Fuca Strait and Strait of Georgia region. The thick, shaded line shows the main transect of stations used in Fig. 26.2, with the numbers giving the distance in km from the mouth of Juan de Fuca Strait.

During the spring survey of 2013, upper layer chl concentrations (Fig. 26.2, right panel) in the Strait of Georgia ranged from 7 to 22 (mg m^{-3}) and were in general lower, similar, and higher than the average concentrations from previous years (2004-2012) in the southern, central and northern region of the Strait, respectively. Upper layer nitrate concentrations during the spring survey (Fig. 26.2, left panel) were about half the average concentration from previous years (2002-2012) in the Strait of Georgia but similar to the average in Juan de Fuca. Low spring nitrate concentrations in the Strait of

Georgia, as those observed during the 2013 survey, are due to phytoplankton growth and thus indicate that the spring bloom started before the survey (April 10) in agreement with the estimated start of the spring bloom in the central Strait of Georgia, derived from MODIS satellite observations (about March 10; Gower, this volume) and plankton model predictions (April 1; Allen et al., this volume).

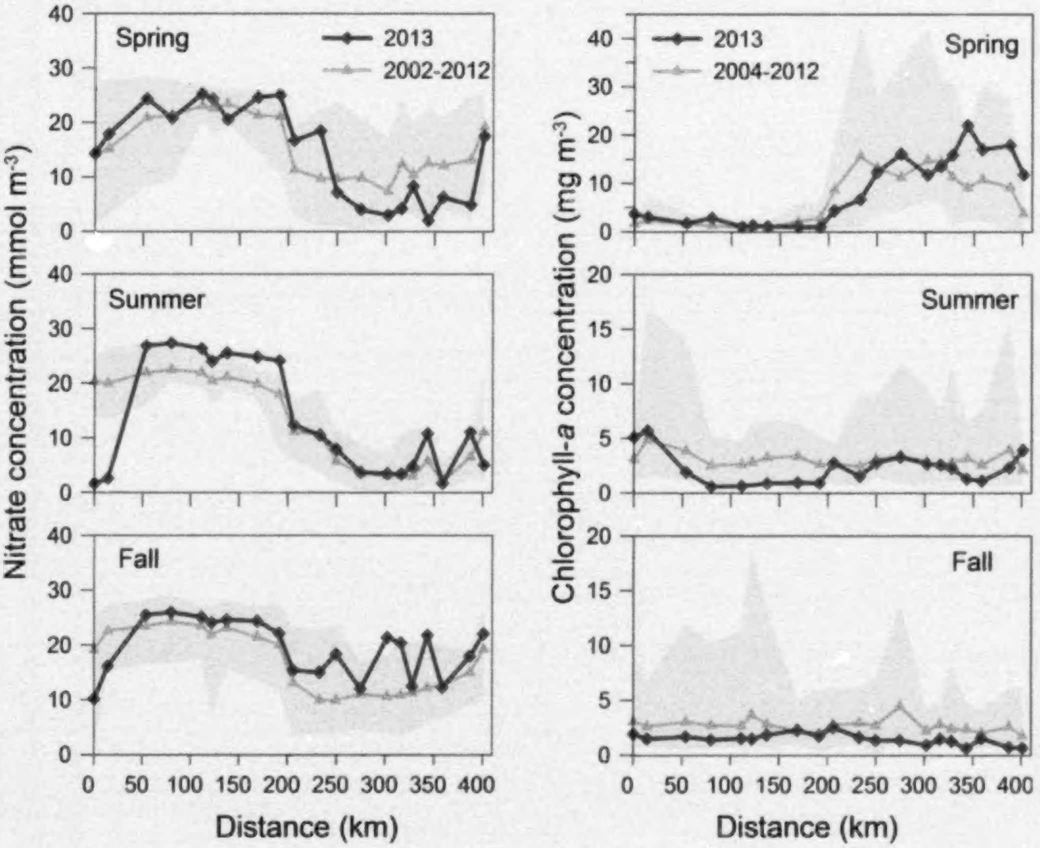

Figure 26.2. Upper layer nitrate (left panel) and chlorophyll (right panel) concentrations along the main transect from the mouth of the Juan de Fuca Strait to the north end of the Strait of Georgia during spring, summer, and fall surveys. Blue diamonds are observations in 2013. Magenta triangles and shaded area denote averages and ranges from 2002 to 2012 for nitrate and 2004 to 2012 for chlorophyll. Numbers along lower axes are cumulative distance from the mouth of the Juan de Fuca Strait (see Fig. 26.1).

During the summer, upper layer chlorophyll and nitrate concentrations in the Strait of Georgia were similar to those observed in previous years. In comparison, summer chlorophyll concentrations were lower and nitrate concentrations higher than average in Juan de Fuca Strait, except at the stations near the mouth where chlorophyll concentrations were high (> 5mg m^{-3}) and nitrate concentrations were the lowest so far observed in this region, being only about 10% of the average concentration from previous years (2002-2012). During the fall survey, similar low chlorophyll concentrations (<2 mg m^{-3}) were observed along the transect, which were mostly lower than the averages from previous years. Nitrate concentrations increase by the fall and were higher than the average from previous years, except at the mouth of Juan de Fuca Strait were they remained lower than in previous years. The significant low nitrate concentrations observed near the mouth of Juan de Fuca Strait were likely due to the input of low nutrient waters from the continental shelf region rather than caused by local consumption of nutrients by phytoplankton.

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27. Fraser Sockeye Salmon Productivity: Forecasts, Indicators, and Uncertainty

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Most Fraser Sockeye Salmon return to freshwater to spawn as four year old fish, after generally spending their first two winters in freshwater, and their last two winters in the ocean. After their second winter in freshwater, Fraser Sockeye smolts migrate downstream in the Fraser River, and enter the Strait of Georgia. They migrate rapidly northward in the Strait of Georgia (Preikshot et al. 2012), and move into the North Pacific via the Johnstone Strait. Fraser Sockeye juveniles continue their northward migration along the continental shelf, move into the North-East Pacific in their first winter at sea (Tucker et al. 2009), and then spend one more winter in the marine environment before they return to their natal spawning grounds as adults.

Considerable Fraser Sockeye mortality occurs in the marine ecosystem, as indicated by Chilko River Sockeye (Fraser Sockeye indicator stock) marine survival data (Fig. 27.1). Chilko is the only Fraser Sockeye stock with a long and complete time series of smolt data (counted through an enumeration weir located at the outlet of Chilko Lake), which can be used with escapement and return data to partition total survival into freshwater and 'marine' components ('marine' survival includes their migration downstream from the counting weir to the Strait of Georgia). 'Marine' survival data for Chilko exhibited declines in the 1990's, which culminated in the lowest survival on record in the 2005 brood year (2009 return year). Subsequently, marine survival has generally improved (Fig. 27.1).

For all other Fraser Sockeye stocks, total survival cannot be partitioned into freshwater and marine components; only total survival can be estimated. Total Fraser Sockeye survival (returns/female spawner), aggregated across all stocks, exhibits a similar trend to that of Chilko Sockeye. Total Fraser Sockeye aggregate survival declined in the 1990's, which culminated in the lowest survival on record in the 2005 brood year (2009 return year), and subsequently has improved (Fig. 27.2). The aggregated Fraser Sockeye survival trend largely represents stocks that comprise the greatest proportion of total Fraser Sockeye abundance, namely Summer Run stocks (based on return timing of adults to their spawning grounds) such as Chilko and Quesnel.

Across the individual Fraser Sockeye stocks, however, there has been considerable variability in survival. Some stocks, such as Early Stuart, exhibited declines in total survival for a much longer period (beginning in the 1960's), while others have not exhibited any systematic survival trends (such as Late Shuswap), and one stock in particular (Harrison Sockeye) has increased in survival in recent years (Fig. 27.3). The common feature amongst all stocks is that survival for the 2005 brood year was below average, and in many cases was the lowest on record, and survival in recent years has been close to average (Fig. 27.3).

Given the wide variability in annual salmon survival (recruits-per-spawner), and the absence of leading indicators of survival, Fraser Sockeye return forecasts are associated with high uncertainty. For Fraser Sockeye, quantitative and qualitative indicators of survival explored to date have not reduced forecast uncertainty and remain an active area of research. The limited understanding of mechanisms affecting Fraser Sockeye survival is due to the broad range of environments these stocks occupy throughout their life-history.

To capture inter-annual random (stochastic) uncertainty largely attributed to Fraser Sockeye survival, return forecasts are presented as standardized cumulative probabilities (10%, 25%, 50%, 75%, and 90%), using Bayesian statistics, rather than as single deterministic point estimates (Grant et al. 2010; DFO 2014). At the 25% probability level, for example, there is a one in four chance the actual return will fall at or below the specified return prediction, given the historical data. Fisheries and Oceans Canada (DFO) fisheries managers use these forecast probability distributions to frame out the range of fishing opportunities that stakeholders may expect in the upcoming year. These return forecasts are also applied, in concert with run timing forecasts, as additional information for test-fishery and hydro-acoustic models, used to manage the fisheries in-season. As the fishing season proceeds and more in-season data become available, the pre-season forecasts have a diminishing influence on in-season return estimates.

The 2014 return forecast indicates a one in ten chance (10% probability) the total Fraser Sockeye return will be at or below 7,237,000 (lowest observed on this cycle) and a nine in ten chance (90% probability) it will be at or below 72,014,000, assuming survival is similar to past observations (DFOa 2014). The mid-point of this distribution (50% probability) is 22,854,000 (there exists a one in two chance the return will be at or below this value). The 2014 forecast falls largely above the cycle average at most probability levels, due to the exceptional escapement in the Shuswap system in the 2010 brood year (this includes Late Shuswap-Adams Sockeye stock and Early Shuswap-Scotch & Seymour stocks). As a result, Shuswap stocks contribute ~70% to the total 2014 forecast.

Given the exceptional brood year escapements in 2010 for Shuswap stocks in particular, a supplement paper was produced as part of the 2014 forecast process (DFOb 2014). This supplement provides additional information on the condition and abundance of various stocks from the 2010 brood year escapement through to 2013 jack returns. Generally, the proportional contributions of major stocks (Late Shuswap, Early Shuswap, Chilko, Quesnel and Stellako) were consistent across the various life-history stages assessed, including the adult escapements in 2010, downstream migration of smolts at Mission from April to May 2012, and Strait of Georgia, and Johnstone Strait juvenile sampling from May to July 2012. The only exception was an increase in the proportion of Quesnel Sockeye in the smolt and juvenile samples, over what was observed on the spawning grounds (DFOb 2014). The abundance of jacks that returned in 2013 was on the higher end of previously observed jack abundances; however, forecasts generated using jacks as a predictor variable were similar (10% to 90% distributions) to DFO's official forecasts for key stocks (Shuswap and Chilko) (DFOb 2014).

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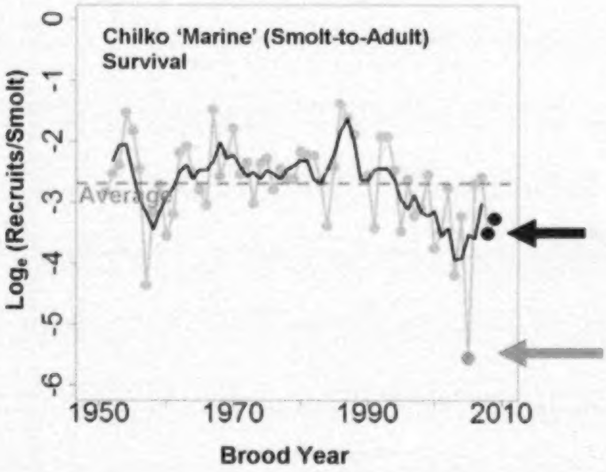
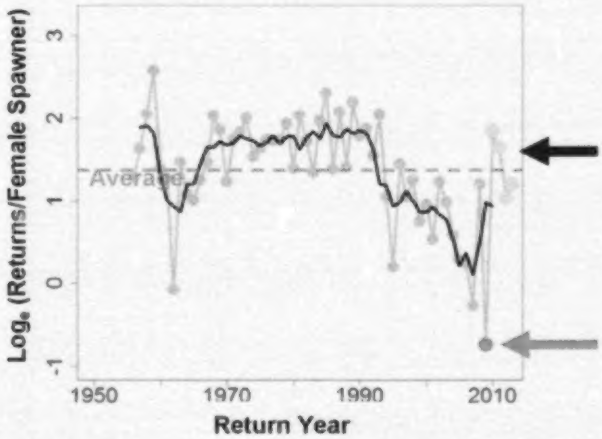


2008 & 2009 brood years
Note: return data are extremely preliminary and age proportions of returns were estimated using forecasts.

2005 brood year
(i.e. 2009 four year old and 2010 five year old returns; lowest survival year on record for most Fraser Sockeye stocks)

Figure 27.1. Chilko River Sockeye 'marine' (log$_e$ recruits-per-smolt) annual survival (filled grey circles and lines) and smoothed four-year running average survival (black line). The 2005 brood year (2009 return year) was the lowest survival observed for Chilko Sockeye (red-filled circle) and the 2006 to 2009 brood years (2010 to 2013 return years; amber-filled circles) are closer to average. Note: Chilko 'marine' survival includes a freshwater period during their downstream migration as smolts from the outlet of Chilko Lake to the Strait of Georgia. The red dashed line indicates average survival.



2010 to 2013 return years
(i.e. 2006 to 2009 brood years)

2009 return year
(i.e. 2005 brood year; lowest
survival year on record for
most Fraser Sockeye stocks)

Figure 27.2. Total Fraser Sockeye survival (log$_e$ (returns/total spawner)) up to the 2013 return year (filled grey circles and lines) and smoothed four year running average (black line). The 2009 return year (2005 brood year) was the lowest survival observed for the Fraser Sockeye aggregate (red filled circle) and the 2010 to 2013 return years (2006 to 2009 brood years; amber filled circles) are closer-to-average survival (2011 to 2013 brood years are based on preliminary recruitment estimates). The red dashed line indicates average survival.

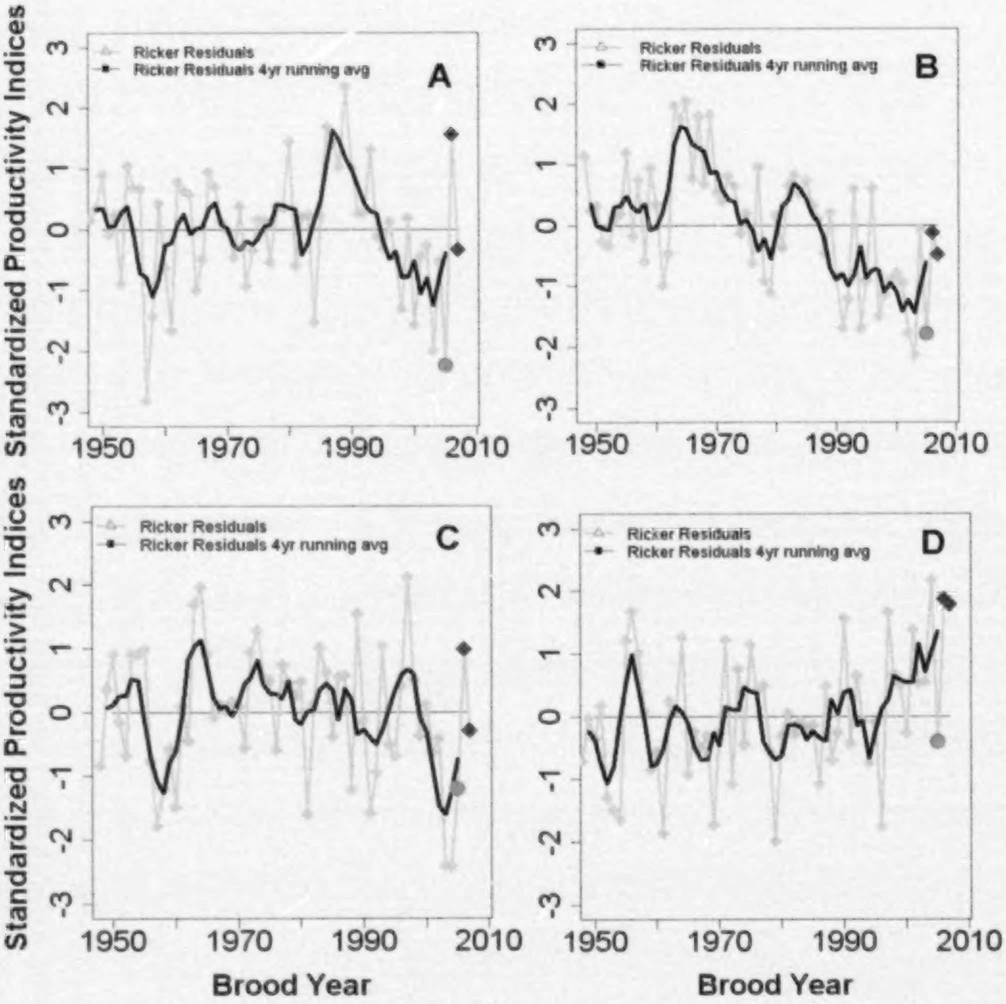


Figure 27.3. Fraser Sockeye survival (standardized z-scores of Ricker model residuals) up to the 2012 return year for ***A.*** *Chilko Sockeye;* ***B.*** *Early Stuart Sockeye;* ***C.*** *Late Shuswap Sockeye; and* ***D****. Harrison Sockeye. The grey filled circles and line presents annual productivity and the solid black line presents the smoothed four-year running average. The 2005 (red circle) and 2006-2007 brood years (blue diamonds) are indicated; these recent data are preliminary.*

28. Juvenile salmon surveys in the Strait of Georgia 2013

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Juvenile salmon generally enter the Strait of Georgia from April to June, many remaining there until the fall. In 2013 juvenile salmon were sampled during trawl surveys June 1-11, June 26-July 6 and September 18 – 29. These surveys fished standard track lines sampled since 1998 following the protocol in Beamish et al. (2010). The June 1-11 survey was conducted using the chartered commercial trawl vessel *Viking Storm*. The subsequent two surveys were conducted with the Canadian Coast Guard Research Vessel *W.E. Ricker*. In this report we use a combination of the catch rates along with oceanographic conditions in the Strait of Georgia to estimate the relative strength of returning adults (return year dependent on species) for juvenile salmon that entered the ocean in 2013. Beamish et al. (2010) reported on the relationship between the catch rates of juvenile Coho Salmon and subsequent adult returns. In this report we apply the same methodology to all juvenile salmon catch rates with the assumption that early marine survival is a major component determining total marine survival. The estimates provided are not for absolute returns but for the relative strength of returns compared to the survey time period.

The surface water temperature (SST) in 2013 was the warmest observed for the May to July time period since 2004 and the fifth highest in the time series (Fig. 28.1). Surface salinity during this early summer period was over 26 psu and higher than the previous few years (e.g. Chandler, 2014). Fraser River discharge in April was similar to 2012 and was within the variability observed over the past 12 years (Fig. 28.2). It is not known how the increase in SST in 2013 during the early summer would impact the productivity conditions in the Strait of Georgia

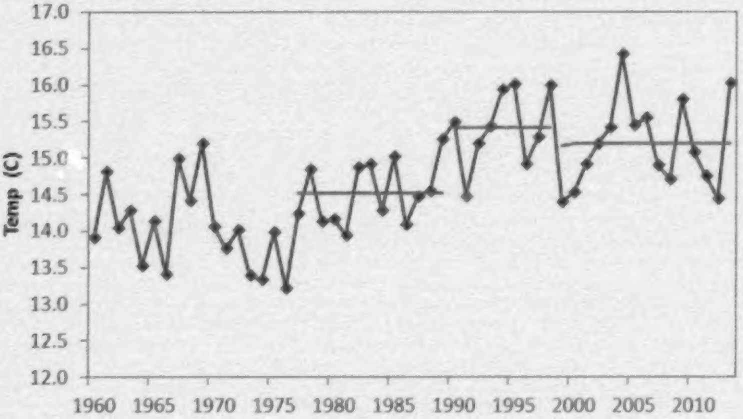

Figure 28.1. Average surface water temperature (SST) in May-July 1960-2013 in the Strait of Georgia. Measurements are averaged from five locations throughout the Strait, including Cape Mudge, Chrome Island, Departure Bay, Entrance Island, and Sisters Island. Data available from http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/index-eng.htm. *The red bars are regime averages.*

for juvenile salmon or if these conditions would influence their residence time and distribution. Although there is some indication that the survival of juvenile salmon may be inversely related to SST (Friedland et al. 2003, Petrosky and Schaller, 2010, Beamish et al. 2009) there is also a suggestion that these ocean conditions explain only a small proportion of the variability in salmon survival driven by environmental factors (Mueter et al. 2005). Therefore, the increase in the SST during early summer 2013 is a note of caution; we do not know the impact on the survival of juvenile salmon entering the ocean in this year.

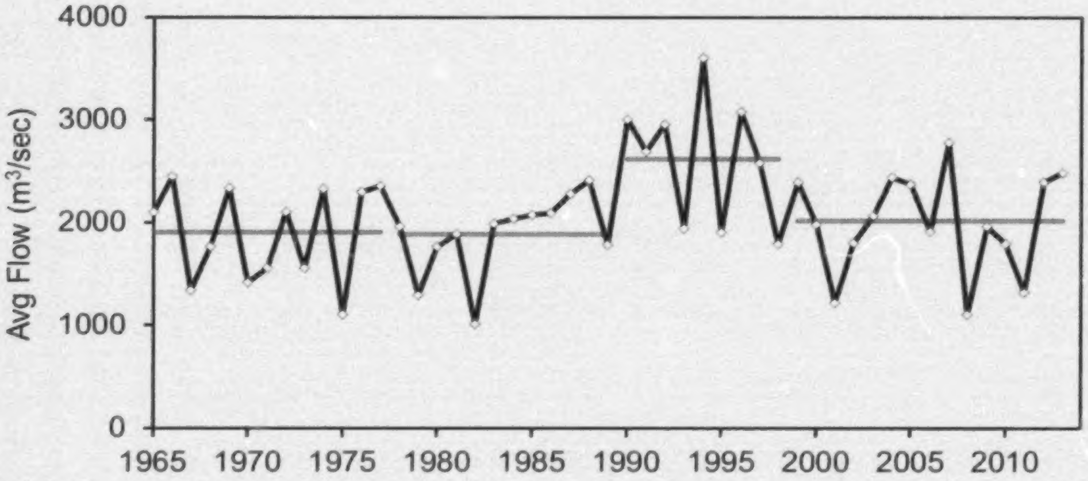

Figure 28.2. Average flow of Fraser River (cubic meters per second) at Hope for April 1965-2013. Data are from station # 08MF005 provided by Water Resources Branch, Environment Canada.

Coho Salmon generally spend one winter in the ocean, therefore, most juveniles that entered the ocean in 2013 will return in 2014. Juvenile Coho Salmon generally remain in the Strait of Georgia until fall (Chittenden et al. 2009) and this region is important in determining brood year strength (Beamish et al. 2010). The CPUE of Coho Salmon in July 2013 was above the time series average (Fig. 28.3A) although the average size was smaller. The CPUE of Coho Salmon in the September 2013 survey was the highest in the time series, exceeding the previous high observed in 2012 (Fig. 28.3B), and the fish were above average in size. This would suggest a **good** return of Coho Salmon to be expected in 2014 although it does not reflect any impact of warmer SST during the early marine period.

Of note in 2013 was the return of adult Coho early in the summer months. Historically, Coho returned to this region and supported a blueback fishery but since the mid-1990s, the behaviour of Coho Salmon changed and this early summer sport fishery collapsed. Beamish et al. (2009) related the proportion of coho salmon captured inside the Strait of Georgia (compared to regions outside the Strait of Georgia) to the winter (February) salinity in the Strait of Georgia. In February 2012 the salinity (29.6 ppm) was the highest since 2000 (30.1 ppm). The salinity in February 2014 in the Strait of Georgia remained high (29.2 ppm) and in combination with the strong CPUE the previous September, may be an indication of a second year in a row of adult Coho Salmon present in the Strait of Georgia in the spring.

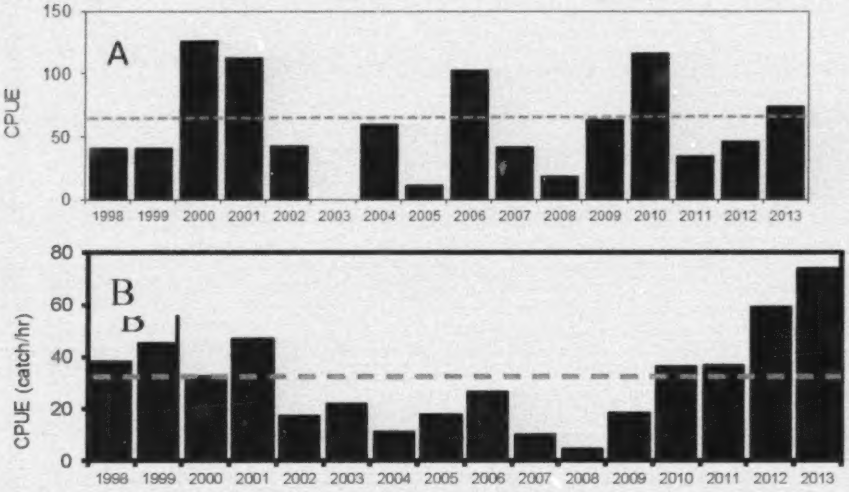

Figure 28.3. CPUE of Coho Salmon in (A) June-July and (B) September 1998-2013 in the Strait of Georgia. Dashed lines are average CPUE for 1998-2013.

Most of the Sockeye Salmon that entered the Strait of Georgia in 2013 were progeny of the Sockeye Salmon which returned to the Fraser River in 2011. This was a sub dominant year and large numbers were not expected. It was, therefore, not surprising that the CPUE of juvenile Sockeye Salmon in the early summer survey was low, however it was a concern that the CPUE was the lowest observed for this cycle year (Fig. 28.4). This low catch in combination with the warm surface water temperatures that the juvenile Sockeye Salmon encountered during their early marine period is concerning and could suggest **average to poor** returns of this cycle year in 2015.

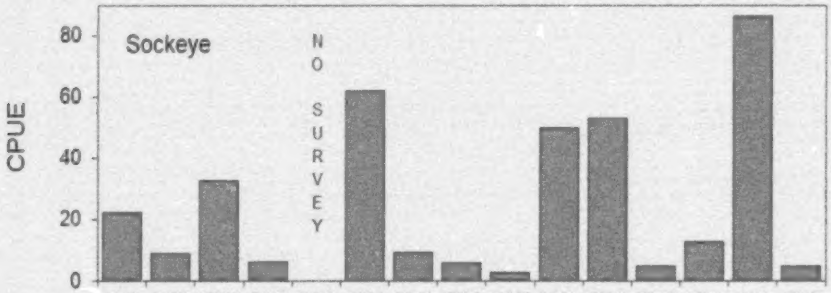

Figure 28.4. CPUE for juvenile Sockeye Salmon caught in the June/July trawl surveys in the Strait of Georgia 1998-2013. Dashed line is average CPUE for 1998-2013.

Chum Salmon enter the ocean in the year they emerge from the gravel and typically spend three winters in the ocean. The CPUE of Chum Salmon that entered the ocean in 2013 and were caught in the early summer survey was low but greater than 2011 and 2012 (Fig. 28.5). Although the trend in CPUE was increasing it remained below the average of the time series and the average size of the juveniles was also low. In addition, the average size of the juveniles remained small. Based on these factors combined we expect **poor** returns of Chum Salmon in both 2015 and 2016.

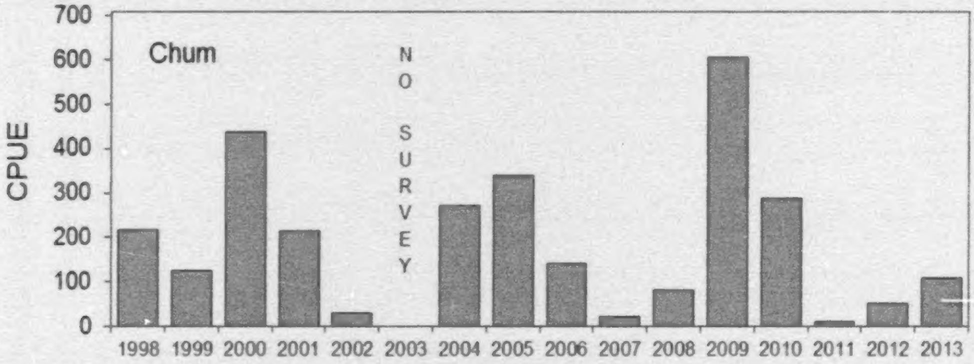

Figure 28.5. CPUE of Chum Salmon in the June-July trawl surveys in the Strait of Georgia 1998-2013.

Chinook Salmon early life history is complex with variation in life history type (ocean and stream-type), age at ocean entry and timing of ocean entry. Results of DNA analysis of Chinook Salmon described in Beamish et al. (2011) indicated that catches in the June/July surveys are a mixture of ocean and stream type Chinook Salmon. The CPUE of Chinook Salmon that entered the ocean in the spring/early summer of 2013 and were caught in the early summer survey continued a declining trend from 2006 and was below the long term average (Fig. 28.6A). The average size of these fish was the largest we had observed in the time series (Fig. 28.6B) but we cannot determine if this is related to shifts in the proportion of ocean and stream type fish without further analysis. Due to the complexity of this species and the large number of variables we do not know what this will mean to overall returns in 2014-2016. However, it is an indication that additional research on factors regulating survival during this early marine period is required.

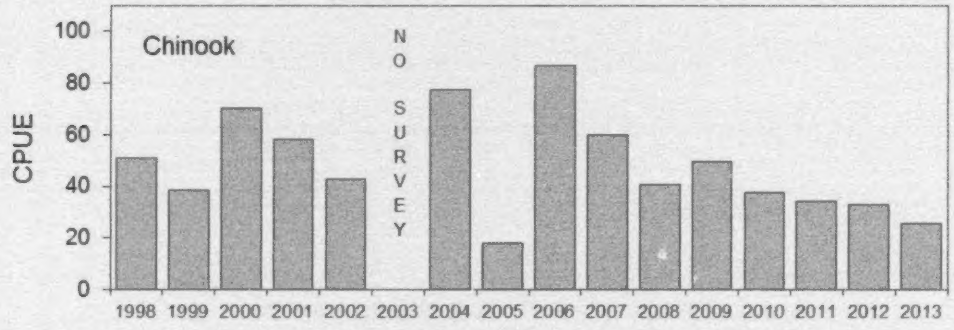

Figure 28.6. (A) CPUE and (B) anomaly of average length of juvenile Chinook Salmon caught in the June/July trawl surveys in the Strait of Georgia 1998-2013.

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29. Telemetry-based estimates of early marine survival and residence time of juvenile Sockeye salmon in the Strait of Georgia and Discovery Passage, 2013

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We used a large-scale acoustic telemetry array to track two year old Chilko Lake Sockeye salmon smolts during the initial 1000 km of their freshwater and marine migration. Salmon smolts were surgically implanted with a uniquely coded acoustic transmitter ("tag") and then tracked with a network of acoustic sensors positioned within the Fraser River basin and at multiple sites in the Salish Sea (Fig. 29.1). By reconstructing the movements of each individual salmon from the data recorded by the array it was possible to estimate survival from Chilko Lake into the Fraser River and through the Strait of Georgia, Discovery Passage and Queen Charlotte Strait using the Cormack-Jolly-Seber model (Cormack 1964; Jolly 1965; Seber 1965) and to determine residence time (transit time) in these key areas. This report focuses on components of the west coast array that are variously managed by Kintama Research Services, the University of British Columbia and the Ocean Tracking Network (OTN).

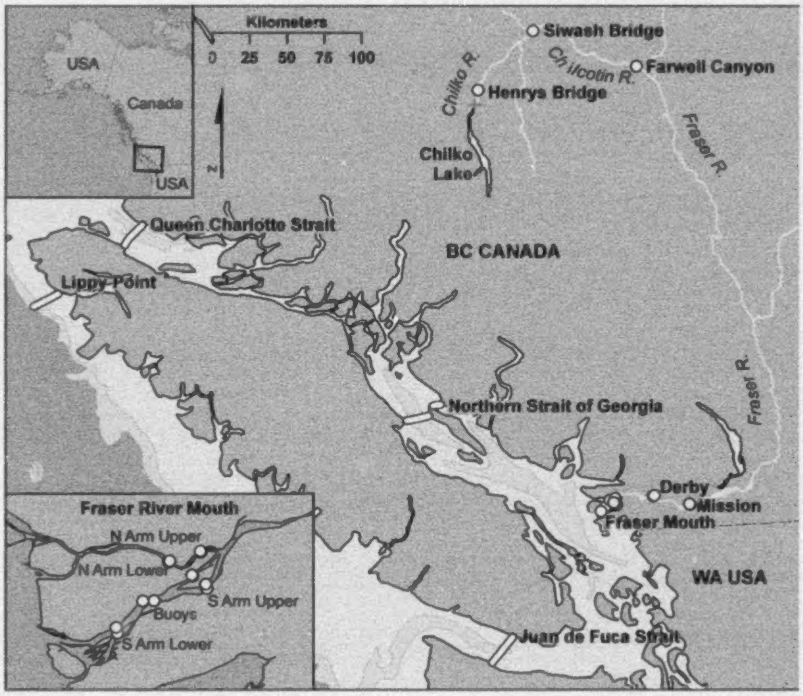

Figure 29.1. Map of the acoustic receiver array (yellow lines and dots) used to track juvenile Chilko Lake (Fraser River) Sockeye salmon. The blue cross represents the Chilko Lake release site in 2010-2013. Isobaths (200 and 500 meter) are coloured in pale blue. The Salish Sea includes Puget Sound to the south, Johnstone Strait to the north and Juan de Fuca Strait to the west. The Lippy Point sub-array was not deployed in 2012 and 2013.

Chilko Lake Sockeye Early Migration Survival Estimates

In 2013, freshwater survival from the DFO counting fence at the outlet of Chilko Lake to the Fraser River mouth was 48% (SE=4%) for smolts tagged with a 7 mm diameter tag (n=203), the highest observed in our four year study. In 2012, freshwater survival was 29% (SE=3%) for smolts tagged with a 7 mm diameter tag (n=386) and 34% (SE=3%) for smolts tagged with a 5 mm tag (n=199), which was consistent with survival in 2011 (31% (SE=4%) and 32% (SE=5%) for smolts tagged with 7 mm (n=254) and 6 mm tags (n=200)). Estimated survival to the river mouth was only 21% (SE=4%) for smolts tagged with 7 mm tags in 2010 (n=199; Fig. 29.2). When survival was estimable at the confluence of the Chilcotin and Fraser rivers, we found that most of the mortality occurred within the first 178 km (in the Chilko and Chilcotin rivers), and very little mortality occurred during the nearly 400 km migration through the Fraser River (see Fig. 29.2; all 2011 treatment types and 2012 V5). This was further demonstrated by an additional treatment group released in 2011: tagged smolts were transported 80 km downstream of the high mortality area in the Chilko River. Mortality in the Chilcotin River was similar to the other treatment groups, but very little mortality occurred once smolts reached the Fraser River (not shown).

Subsequent survival from the Fraser River mouth through the Strait of Georgia for smolts tagged with 7 mm tags was high in three of four years: 82% (SE=23%) in 2013, 77% (SE=18%) in 2012, 76% (SE=23%) in 2010. Survival in the Strait of Georgia was lowest in 2011 (38%, SE=10%, for V7 tagged smolts excluding transported smolts; 5 mm and 6 mm tags could only be detected in freshwater).

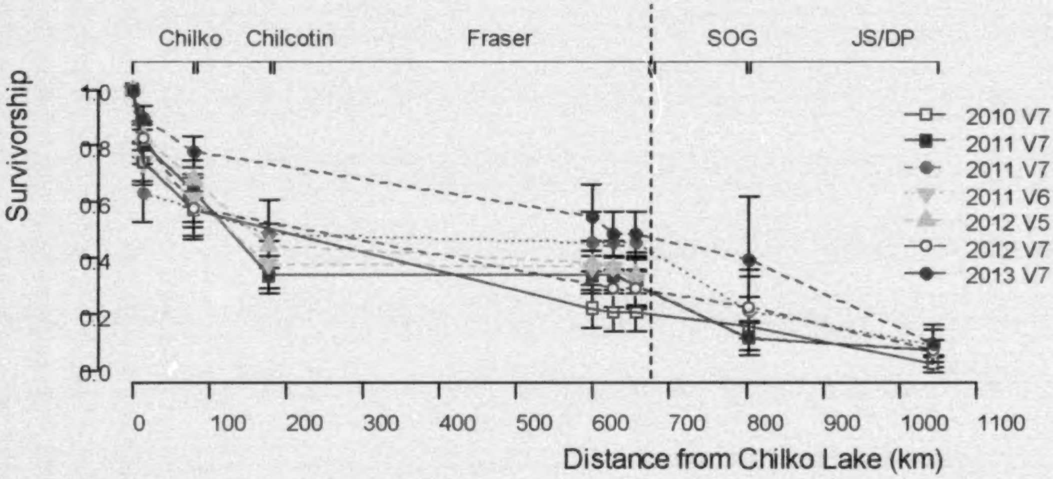

Figure 29.2. Cumulative survival of wild, two-year-old Chilko Lake Sockeye smolts from release at the DFO counting fence near the outlet of Chilko Lake to Queen Charlotte Strait (QCS; NE Vancouver Island). SOG=Strait of Georgia, DP/QCS=Johnstone Strait/Queen Charlotte Strait. Smolts were implanted with 5 mm, 6 mm, or 7 mm diameter VEMCO transmitters (5 mm and 6 mm tags could only be detected in freshwater). In 2011, smolts were released at the DFO fence (2011 V7 (1)), and a group of smolts was transported via truck and then released near the fence (2011 V7 (2)) as a control group for smolts that were transported downstream (not shown). The dashed vertical line represents the Fraser River mouth. Error bars are 95% confidence intervals. In 2010 and 2012 we could not separate Chilcotin and Fraser River survival for smolts tagged with 7 mm tags because either receivers were not deployed (2010) or did not detect smolts at that location (2012).

Survival from the northern Strait of Georgia through Discovery Passage and much of Queen Charlotte Strait was variable: 24% (SE=9%) in 2013, 31% (SE=10%) in 2012, 61% (SE=18%) in 2011, and 17% (SE=9%) in 2010. Early marine survival in the two marine migration segments combined was 20% (SE=5%) in 2013, 24% (SE=6%) in 2012, 23% (SE=7%) in 2011, and 13% (SE=8%) in 2010.

Cumulative smolt survival from Chilko Lake to northern Vancouver Island, a distance of 1044 km, was lower than expected: 10% (SE=3%) in 2013, 7% (SE=2%) in and 2011 and 2012, and only 3% (SE=2%) in 2010 (Fig. 29.2). Survival estimates may have been underestimated due to weakening tag output by the time smolts reached the QCS sub-array or additional mortality due to tagging. No smolts were detected migrating via the southern route through Juan de Fuca Strait in 2010, 2012, or 2013. In 2011, three smolts were detected on the Juan de Fuca Strait sub-array; two of these three fish were later detected on the Lippy Point sub-array on the northwest end of Vancouver Island.

2013 was the fourth year for which we estimated survival of wild Chilko Lake Sockeye smolts; however, in 2004-07, we made similar measurements for young hatchery-reared Cultus Lake sockeye salmon migrating down the Fraser River and through the Salish Sea, including the crucial 2007 smolt outmigration year which led to extremely low returns in 2009 (see Welch et al. 2009). Thus, we now have eight years of direct, telemetry-based survival measurements for Sockeye smolts along the inner coast of Vancouver Island. As with Chilko smolts, early marine survival of Cultus Lake smolts was variable: survival in the Strait of Georgia (SOG) ranged between 38-92%, and 37-60% through Discovery Passage and much of Queen Charlotte Strait.

Sockeye Daily Survival Rates

Daily survival rates of Chilko Lake Sockeye in freshwater were lower than Cultus Lake sockeye (Fig. 29.3), presumably due to the high mortality experienced over a short period of time in the Chilko and Chilcotin rivers (Fig. 29.2). Chilko Sockeye smolts had consistently higher and somewhat more stable daily survival rates in the SOG in all years relative to freshwater, and these survival rates were similar to survival rates measured for Cultus Lake sockeye in prior years. Subsequent rates of survival during migration through the Johnstone Strait, Discovery Passage, and Queen Charlotte Strait region were generally lower and more variable than in the SOG for both Chilko and Cultus Lake smolts.

Chilko Smolt Residence Time in the Strait of Georgia and Queen Charlotte Strait

Travel time from Chilko Lake to the Fraser River mouth was approximately one week in all years (median travel time ranged from 5-9 days). Median travel time through the Strait of Georgia (Fraser River mouth to the Northern Strait of Georgia (NSOG) sub-array, 147 km) was 10 days in 2013, 16.4 days in 2012, 18.6 days in 2011 and only 9.1 days in 2010 (Fig. 29.4) and 95% of smolts had passed the NSOG sub-array by June 3rd in 2013, June 7th in 2012, June 12th in 2011 and June 16th in 2010 indicating that two year old smolts migrate quickly through the SOG by mid-June (i.e. brief residence time). Travel time through Discovery Passage and QCS (from the NSOG sub-array to the QCS sub-array, 240 km) was even more rapid: 15 days in 2013, 14 days in 2012, 10.8 days in 2011 and 9.4 days in 2010. 95% of smolts had reached the northern Queen Charlotte Strait by June 17th in 2013, June 16th in 2012, June 23rd in 2011 and June 28th in 2010.

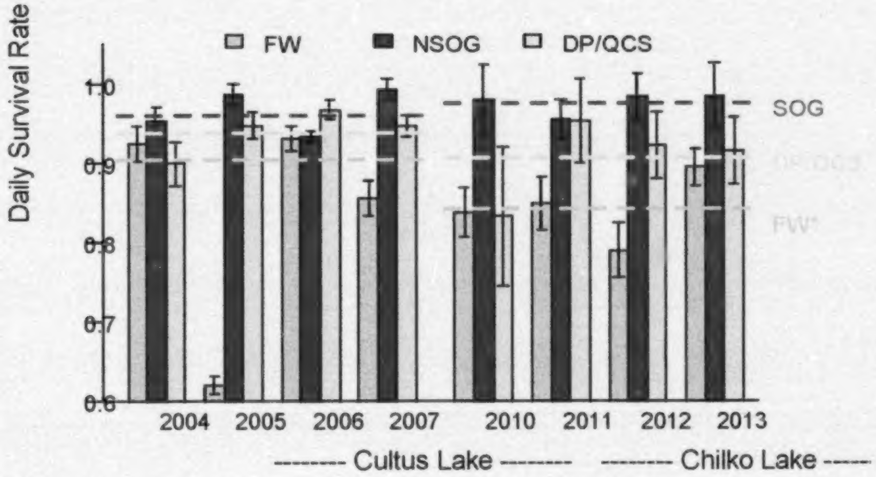

*Figure 29.3. Daily survival rate for two-year-old hatchery-reared Cultus and wild Chilko Lake Sockeye smolts in the Fraser River basin (FW), Strait of Georgia (SOG) and Discovery Passage/Queen Charlotte Strait (DP/QCS). The six dashed horizontal lines indicate the multi-year average survival rate for each population in each of three habitats. *The FW average excludes 2005 Cultus Lake sockeye survival ((see* Welch, et al. 2009). *Error bars show 95% confidence intervals.*

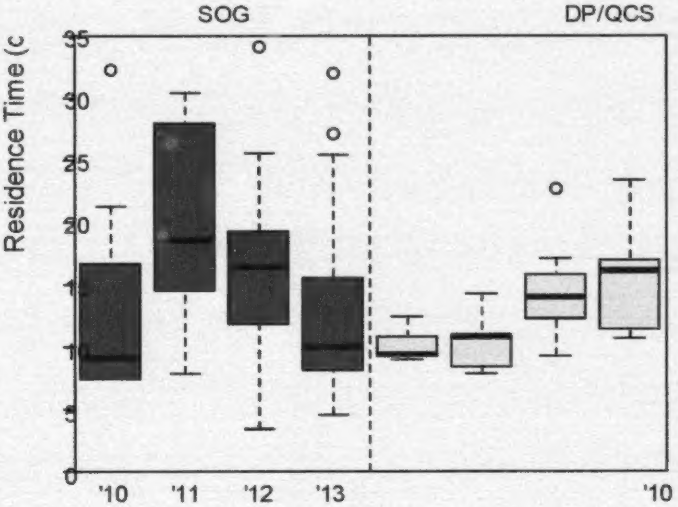

Figure 29.4. Residence time of acoustic tagged two-year-old Chilko Lake Sockeye smolts in the Strait of Georgia (SOG) and Johnstone Strait/Queen Charlotte Strait (DP/QCS), 2010-2013 . The central band within the box is the median, the top and bottom side of each box are the 25th and 75th percentiles, and the whiskers extend to the minimum and maximum values exclusive of outliers. Outliers are beyond 1.5 times the interquartile range and are shown as open circles.

Summary

Our multi-year results indicate that survival patterns of Chilko Lake Sockeye smolts are consistent among years, in that freshwater mortality appears to be largely confined to clearwater tributaries leading to Fraser, presumable due to predation, and survival down the Fraser River mainstem is very high. Once in the ocean, mortality increases between NSOG and QCS. Daily survival rates are lowest in freshwater (Fraser tributaries) and between the NSOG and QCS. Survival rates are highest in the SOG. Transit times indicate that large smolts rapidly migrate out of the SOG and QCS.

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30. The Salish Sea MEOPAR Project

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The Salish Sea is home to a large population of Canadians living in coastal communities at risk to ocean related hazards. There is an ongoing need to assess the impact of these hazards on human and marine environments through a multidisciplinary approach involving Canadian oceanographers, biologists, and social scientists. The Marine Environmental Observation Prediction and Response network (MEOPAR: MEOPAR.ca), a Canada Network of Centres of Excellence, provides a platform to accelerate this type of research.

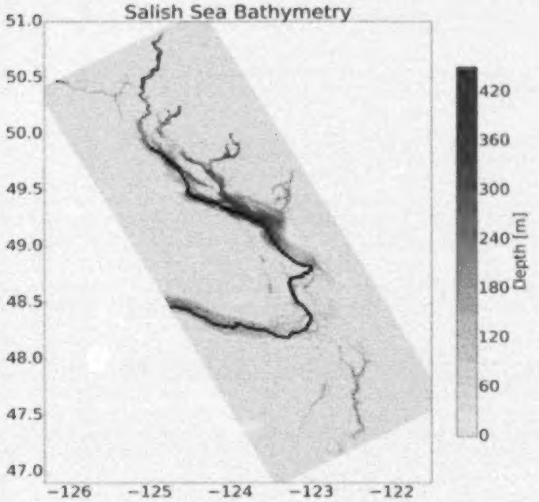

Figure 30.1. Model domain (Salish Sea comprised of the Strait of Juan de Fuca, Puget Sound, and the Strait of Georgia) and bathymetry.

The Salish Sea MEOPAR project team is developing a three-dimensional ocean model for the Salish Sea, which includes the Strait of Georgia. Using the NEMO modelling architecture (Madec 2008) this Salish Sea model will be used to evaluate storm surge risk in coastal communities. Long term goals include data assimilation from the VENUS (venus.uvic.ca) network and a coupled biogeochemical modelling component.

The model domain includes the Strait of Juan de Fuca, Puget Sound, and the Strait of Georgia (Fig. 30.1). The computational domain is divided into 900 by 400 by 40 grid cells. The model includes fresh water input from 150 rivers, forcing by eight tidal constituents, open boundary conditions at the Juan de Fuca and Johnstone Strait boundaries, and atmospheric wind and pressure forcing at the ocean surface. To facilitate collaboration, the team uses a combination of the IPython Notebook, distributed version control, and the Notebook Viewer service (nbviewer.ipython.org). This set of tools enables sharing of model output such as visualization and analysis of results. An example of the salinity field is shown in Fig. 30.2.

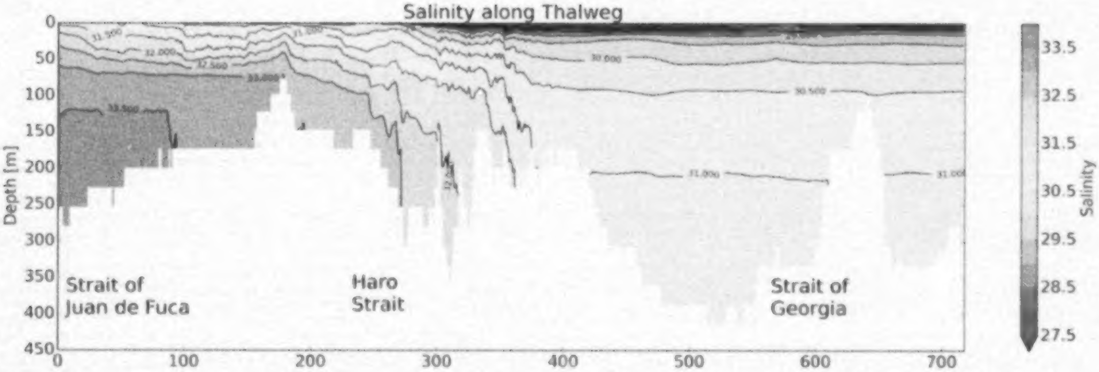

Fig. 30.2. Salinity field from model output along the thalweg. The thalweg curve is the black line through the centre of the marine environment in Fig. 30.1.

This multidisciplinary project funded by MEOPAR involves collaboration among scientists across Canada. The Salish Sea modelling component is led by Dr. Susan Allen in the Department of Earth, Ocean, and Atmospheric Sciences at the University of British Columbia. The project has been developed in collaboration with the Dr. Youyu Lu group at the Bedford Institute of Oceanography and the Dr. Keith Thompson group at Dalhousie University. Up-to-date model details can be found at: http://salishsea-meopar-docs.readthedocs.org

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Appendix 1

DFO State of the Pacific Ocean Meeting
Assessing NE Pacific ocean conditions in 2013

Seminar Room, Pacific Biological Station
3190 Hammond Bay Road, Nanaimo, BC

Agenda

19 February 2014, 0900 - 1700
Chair: Ian Perry (Ian.Perry@dfo-mpo.gc.ca)

NOTE: Participants who are not on the schedule to speak are welcome to bring a poster about their work.

(Mostly) Global, Deep-Sea, West Coast Vancouver Island	
Ian Perry	Welcome, introductions, purpose of meeting; short discussion on how to make the findings more widely available
Bill Crawford	Changing climate and temperature in the Gulf of Alaska
Howard Freeland	The NE Pacific in 2013 – the view from Argo
Jim Gower	NE Pac SST and Chlorophyll, and SoG spring bloom timing in 2013
Faron Anslow	Land-surface weather during the past year in BC
Peter Chandler	Trends in sea surface temperature and salinity at BC lighthouses, 2013
Sonia Batten	Status of lower trophic levels offshore in 2013
Moira Galbraith	Zooplankton update, WCVI and SoG
Richard Dewey/Steve Mihaly	Ocean Networks Canada: Update on key observations from NEPTUNE and VENUS
Marc Trudel	Highlights from the High Seas Salmon Program
Pelagic Ecosystem Monitoring Team (Jennifer Boldt presenting)	Update on pelagic fishes
Ian Perry	Small mesh multispecies trawl survey results for 2013 along WCVI
Kim Hyatt	Coast-wide status of sockeye indicator stocks in 2013 and trends expected from 2013-2016
John Holmes	Albacore update
James Pilkington	North Pacific Right Whales in Canadian Waters: Recent sightings and resulting questions
(Mostly) Strait of Georgia	
Susan Allen	Timing of the Spring Bloom in the Strait of Georgia, and pH and aragonite saturation
Angelica Peña	Observations of phytoplankton in the Strait of Georgia in 2013
Maycira Costa	2002-2013 Chlorophyll dynamics in the SoG based on MODIS imagery
Chrys Neville	Juvenile salmon in Strait of Georgia

Sue Grant	Forecasts and Fraser Sockeye survival trends
Erin Rechisky/David Welch	Telemetry-Based Estimates of Early Marine Survival and Residence Times of Juvenile Sockeye Salmon in the Strait of Georgia and Discovery Passage, 2013
Ian Perry	General discussion of overall trends and events; Close
POSTERS (unscheduled)	
Nancy Sootiens	Developing a full 3-d model of the Salish Sea

Appendix 2

Workshop Participants

Ian Perry	DFO, Pacific Biological Station, Nanaimo
Jim Irvine	DFO, Pacific Biological Station, Nanaimo
Faron Anslow	University of Victoria, Victoria
Dave Blackbourn	DFO (retired)
Louise de Mestral Bezanson	DFO, Simon Fraser University, Burnaby
Richard Dewey	University of Victoria, Victoria
Greg Crawford	Vancouver Island University, Nanaimo
Bill Crawford	DFO, Institute of Ocean Sciences, Sidney (retired)
Kim Hyatt	DFO, Pacific Biological Station, Nanaimo
Frank Whitney	DFO, Institute of Ocean Sciences, Sidney (retired)
Karin Bodtker	Living Oceans Society, Vancouver
Chrys Neville	DFO, Pacific Biological Station, Nanaimo
Hussein Alidina	WWF, Vancouver
Alex Barron	Canadian Parks and Wilderness Society, Vancouver
Susan Allen	University of British Columbia, Vancouver
Nancy Sootiens	University of British Columbia, Vancouver
Jennifer Boldt	DFO, Pacific Biological Station, Nanaimo
Sonia Batten	SAHFOS, Nanaimo
David Welch	Kintama Research, Nanaimo
Angelica Peña	DFO, Institute of Ocean Sciences, Sidney
Charles Hannah	DFO, Institute of Ocean Sciences, Sidney
Moira Galbraith	DFO, Institute of Ocean Sciences, Sidney
Leslie Brown	ASL Environmental, Sidney
Eddie Loos	ASL Environmental, Sidney
Scott Akenhead	S4S, Ladysmith
Wolfgang Carolsfeld	DFO, Pacific Biological Station, Nanaimo
John Holmes	DFO, Pacific Biological Station, Nanaimo
Skip McKinnell	PICES, Victoria (retired)
Isobel Pearsall	Pacific Salmon Foundation, Vancouver (Contractor)
Peter Chandler	DFO, Institute of Ocean Sciences, Sidney
Greg Jones	Environment Canada, Sidney
Brenda Waddell	DFO, Pacific Biological Station, Nanaimo
Hawsun Sohn	DFO, Pacific Biological Station, Nanaimo
John Morris	DFO, Institute of Ocean Sciences, Sidney
Marc Trudel	DFO, Pacific Biological Station, Nanaimo
Jackie Detering	DFO, Pacific Biological Station, Nanaimo
Erin Porszt	DFO, Nanaimo
Diana Dobson	DFO, Nanaimo
Andrew Edwards	DFO, Pacific Biological Station, Nanaimo
Evgeny Pakhomov	University of British Columbia, Vancouver
Lyse Godbout	DFO, Pacific Biological Station, Nanaimo
Erin Rechisky	Kintama Research, Nanaimo
Stephanie King	Seathis Consulting, Nanaimo

Sue Grant	DFO, Delta
Doug Latornell	University of British Columbia, Vancouver
Lingbo Li	University of British Columbia, Vancouver
Jim Gower	DFO, Institute of Ocean Sciences, Sidney
Robin Brown	DFO, Institute of Ocean Sciences, Sidney
Bruce McCarter	DFO, Pacific Biological Station, Nanaimo
Maycira Costa	University of Victoria, Victoria
Howard Freeland	DFO, Institute of Ocean Sciences, Sidney (retired)
James Pilkington	DFO, Pacific Biological Station, Nanaimo
Dennis Chalmers	Province of B.C., Nanaimo
Doug Hay	DFO, Pacific Biological Station, Nanaimo (retired)